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CRYSTALLOGRAPHY

AN ELEMENTARY MANUAL FOR THE LABORATORY

BY

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WITH 6 TABLES, 25 PLATES, AND 812 FIGURES

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ONE OF GOD'S NOBLEST WORKS,

AN HONEST MAN.

INTRODUCTION

CRYSTALLOGRAPHY can be studied from two different view-points: one as a mathematical science with its applications both in the instrumental determination of crystal angles and in their mapping or projection; the other chiefly as an observational study with the application of some simple rules that will enable the prospector and laboratory student to determine the crystalline form with sufficient accuracy for practical purposes in the field or laboratory. It is the intention here simply to devote our time to the latter practical purpose, which is all that the average engineering or science student, who is not making a specialty of Crystallography and Mineralogy, has time to accomplish.

In the study of this subject I worked out a course of brief lectures in 1873, and used them in laboratory work at Harvard University. Subsequently, in 1876 and in later years, they were given in connection with my lectures upon Mineralogy in that institution. These lectures form the nucleus of this little work. With but little modification they were given after-

wards at Colby University, 1885–1887; and at the Michigan College of Mines (formerly the Michigan Mining School), from 1887 for a number of years, until I turned the work over to my assistant, Dr. H. B. Patton, placing my lecture notes in his hands. The principal and essential features of these lecture notes were the rules for the determination of the forms by the relation of the planes to the crystallographic axes. They were originally worked out by me in 1873, and I have never seen them in print anywhere, except when Dr. Patton in 1893 published the lecture notes he had used at the Michigan College of Mines. A second enlarged edition of his book was published by Dr. Patton in 1896, and a third in 1905. Unfortunately, Dr. Patton failed to acknowledge the source whence those rules were obtained.

It has been my intention for over thirty years to elaborate and publish my notes for the use of my students, but as my time has been fully occupied in other work, principally in development work and in executive duties, as well as in original investigation, very little time has been available in which to prepare my notes for publication. Even now, on account of the present demands upon my time, but little elaboration can be made. These notes are published now primarily for use in my own classes, containing over one hundred students in Mineralogy. It is hoped,

however, that they will be useful to other teachers, who, under similar circumstances, are required to give instruction in Crystallography, Mineralogy, and kindred sciences, as a means to an end, and not as subjects to be studied purely for themselves. Such a practical purpose comes naturally as the result of the present tendency of industrial education. It is now required that the fundamental sciences be reduced to the minimum, in order that in four years the student may receive not only his general culture and intellectual furnishing, but that he may also obtain the maximum amount of training in the practical application of the sciences to his future engineering or technical occupation.

My notes have been presented in the form of lectures in THE PENNSYLVANIA STATE COLLEGE since 1901, and until recently I have followed the more common custom of starting with the Isometric System; but experience has led me to believe it is best to develop the work in the reverse order, beginning with the Triclinic System. While the original notes form the essential basis of this work, there will be this difference: the original notes for lecture purposes formed simply a skeleton, and any additional explanations were given orally by the instructor. In the case of this book the necessary explanatory matter has been added to a considerable extent.

Instruction in Crystallography presupposes the use of a collection of natural crystals and of crystal models, as well as personal instruction in the laboratory. In case such collections can not be had, models can be cut out of soft wood like cedar, or out of chalk. They can be made also from putty or clay and dried. Perishable ones can be cut out of potatoes or turnips or some other suitable vegetable.

The glass, paper and wooden models for sale by Dr. F. Krantz, Bonn-am-Rhein, Germany, and other German dealers, are excellent, and every laboratory should be well stocked with them. Smaller collections are for sale by the Foote Mineral Company, Philadelphia; Otto Kuntze, Iowa City, Iowa; and Ward's Natural Science Establishment, Rochester, N. Y. The larger foreign collections can be imported by the above-mentioned firms, as well as by others, for the institutions or individuals desiring them. Natural Crystals can be obtained from the above firms or from any other dealers in minerals.

The methods of instruction I have employed in Crystallography and Mineralogy were detailed in a paper read before the Society of Naturalists in 1883, and published in the *Popular Science Monthly* during the following year (pages 454–459). After a long experience with these methods it appears that the best results have been obtained by first going over care-

fully one crystal system and studying a selected set of models in that system. After the pupil has familiarized himself with the general characters and forms in that system, he has been given a large collection of unlabeled models of that system. After working them out, he has then been given an individual recitation upon these forms, his errors have been corrected, and all points of obscurity have been explained to him. The same method has then been followed with another system, and so on, until the entire six systems, including their twin forms, are understood, so far as the crystal models are concerned.

The student has then been assigned drawers containing models of every system mixed together, so that he will learn to distinguish the forms of one system from those of another. After this he has been assigned natural crystals belonging to each system for his personal study, following the same method as with the models; and then he has been handed a mixed set of natural crystals of every system. The method will naturally have to be varied in each case according to the number of crystals or models each instructor has at his disposal.

There seems to be no way of teaching the student to know the things he is studying except the laboratory or field method, as mere theory is of but little avail in the practice of the engineer or mining

geologist, when he needs to know what is the mineral he has found.

The student who wishes to carry the study of Crystallography further will find help in the excellent chapter upon this subject in Brush and Penfield's "Manual of Determinative Mineralogy and Blowpipe Analysis," John Wiley & Sons, New York, or in the following valuable works:

Bauerman, "Systematic Mineralogy," Longmans, Green & Co., London, 1881.

Dana, "Text Book of Mineralogy," 3rd Ed., John Wiley & Sons, New York, 1898.

Gurney, "Crystallography," Society for Promoting Christian Knowledge, London. No date.

Hilton, "Mathematical Crystallography," Clarendon Press, Oxford, 1903.

Kraus, "Essentials of Crystallography," Ann Arbor, 1906.

Lewis, "Treatise on Crystallography," University Press, Cambridge, England, 1899.

Miers, "Mineralogy," Macmillan & Co., London, 1902.

Miller, "A Tract on Crystallography," Deighton, Bell & Co., Cambridge, England, 1863.

Milne, "Notes on Crystallography and Crystallo-physics," Trübner & Co., London, 1879.

Moses, "The Characters of Crystals," D. Van Nostrand Co., New York, 1899.

Moses and Parsons, "Elements of Mineralogy, Crystallography and Blowpipe Analysis," 2nd Ed., D. Van Nostrand Co., New York, 1904.

Patton, "Lecture Notes on Crystallography," 3rd Ed., D. Van Nostrand Co., New York, 1905.

Story-Maskelyne, "Crystallography," Clarendon Press, Oxford, 1895.

Williams, "Elements of Crystallography," Henry Holt & Co., New York, 1890.

Woodward, "Crystallography for Beginners," Simpkin, Marshall, Hamilton, Kent & Co., London, 1896.

In the German and the French, among the more recent works, the attention of the student may be called to the following:

Bauer, "Lehrbuch der Mineralogie," 2 A., 1904.

Bravais, "Études crystallographiques," 1866.

Brezina, "Methodik der Krystallbestimmung," 1883.

Bruhns, "Elemente der Krystallographie," 1902.

Des Cloizeaux, "Leçons de cristallographie," 1861.

Frankenheim, "Zur Krystallkunde," 1869.

Friedel, "Cours de Mineralogie," 1893.

Goldschmidt, "Krystallographische Projectionsbilder," 1887.

Goldschmidt, "Index der Krystallformen der Mineralien," 1886–1891.

Groth, "Physikalische Krystallographie," 1905.

Hecht, "Anleitung zur Krystallberechnung," 1893.

Heinrich, "Lehrbuch der Krystallberechnung," 1886.

Hochstetter and Bisching, "Leitfaden der beschreibenden Krystallographie," 1868.

Joerres, "Eine Abhandlung über Krystallographie," von W. H. Miller, 1864.

Karsten, "Lehrbuch der Krystallographie," 1861.

Klein, "Einleitung in die Krystallberechnung," 1876.

Klockmann, "Lehrbuch der Mineralogie," 4 A., 1907.

Knop, "System der Anorganographie," 1876.

Kobell, "Zur Berechnung der Krystallformen," 1867.

Kopp, "Einleitung in die Krystallographie, mit einem Atlas," 1862.

Krejči, "Elemente der mathematischen Krystallographie," 1887.

Lang, "Lehrbuch der Krystallographie," 1866.

Lapparent, "Cours de Mineralogie," 3rd Ed., 1899.

Liebisch, "Geometrische Krystallographie," 1881.

Liebisch, "Physikalische Krystallographie," 1891.

Liebisch, "Grundriss der physikalischen Krystallographie," 1896.

Linck, "Grundriss der Krystallographie," 1896.

Lion, "Traité élémentaire cristallographie géométrique," 1891.

Mallard, "Traité der cristallographie," 1879.

Martius-Matzdorff, "Die Elemente der Krystallographie," 1871.

Naumann-Zirkel, "Elemente der Mineralogie," 14 A., 1901.

Nies, "Allgemeine Krystallbeschreibung," 1895.

Quenstedt, "Grundriss der bestimmenden und rechnenden Krystallographie," 1873.

Renard et Stoeber, "Notions de Mineralogie, 1900.

Rose-Sadebeck, "Elemente der Krystallographie," Band I., 1873.

Sadebeck, "Angewandte Krystallographie," 1876.

Schoenflies, "Krystallsysteme und Krystallstructur," 1891.

Schrauf, "Lehrbuch der Krystallographie," 1866.

Sohncke, "Entwicklung einer Theorie der Krystallstructur," 1879.

Sommerfeldt, "Geometrische Kristallographie," 1906.

Sommerfeldt, "Physikalische Kristallographie," 1907.

Soret, "Eléments de crystallographie physique," 1893.

Tschermak, "Lehrbuch der Mineralogie," 6 A., 1905.

Twrdy, "Methodischer Lehrgang der Kristallographie," 1900.

Viola, "Grundzuege der Kristallographie," 1904.

Websky, "Anwendung der Linearprojection zur Berechnung der Krystalle," 1886.

Werner, "Leitfaden zum Studium der Krystallographie," 1867.

Wülfing, "Tabellarische Uebersicht der einfachen Formen 32 krystallographischen Symmetriegruppen," 1895.

Wyrouboff, "Manuel pratique de cristallographie," 1888.

To many of the older works, especially those of Miller and Naumann, every student of Crystallography needs to refer, as well as to the writings of James D. Dana. The author has been indebted greatly not only to them, but also to very many of the works cited above, and to the lectures and writings of Cooke.

Obviously the training in Crystallography, as in every other subject, should not proceed by making the principles obscure, but rather by having them clearly and easily understood. The student should obtain his knowledge of the subject and his mental discipline by applying these principles in actual practice. In the practical application he should be thoroughly questioned to see that he has not only mastered the principles but can readily and understandingly apply them in the laboratory and field.

The text in "Language Studies" and the examples in Mathematics furnish laboratory practice for students in those subjects, but in "Nature Studies" the objects must be supplied and worked over in the laboratory or field; otherwise the pupil better be employed in learning one of Webster's orations, instead of memorizing words that he knows nothing about. Recitation in "Science Study" without laboratory or field training amounts to mere declamation, whether the teaching is given in the primary school or in the college or university.

To repeat: the study of Crystallography with models and natural crystals can be made pleasant and interesting, but without them the study is in the nature of a farce—unless pursued purely as a branch of Mathematics. Similar methods to those mentioned for Crystallography I have employed with excellent re-

sults in Mineralogy and Petrography; and by my direction they were used with similar satisfactory results in the study of Zoölogy and Paleontology, taught by my assistant, now Professor, A. E. Seaman, at the Michigan College of Mines. These principles seem capable of a much more extended use in scientific, technical, and practical education. It is my expectation to publish similar lecture notes on Mineralogy and Petrography.

In a subject so thoroughly worked over as Crystallography has been, nothing original can be expected in so elementary a text as this, except possibly in its effort to lessen the student's labor and thus save him time. If it can enable engineering and scientific students to grasp readily as much of the principles of Crystallography as they need for their subsequent Mineralogical work, its purpose will have been accomplished. The first nine chapters are intended to be used for laboratory work and for recitation, and the last three for reference and illustration.

In trying to make matters clear to a student one is apt to forget that the pupil has not the same familiarity with the various steps in the process as has the writer. This book is an attempt to smooth the way for the pupil as far as practicable.

The author will be very glad to receive the suggestions of other teachers of this subject, and will be

sincerely grateful to anyone who will point out to him such parts of his book as are not entirely clear or accurate.

M. EDWARD WADSWORTH.

THE PENNSYLVANIA STATE COLLEGE,
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NOTES ON CRYSTALLOGRAPHY

CHAPTER I

PRELIMINARIES

ALL students of the sciences know that the natural objects of this earth are divided into three kingdoms: *Animal*, *Vegetable*, and *Mineral*. The first comprises all animals; the second includes every plant; and the third all other materials such as minerals and mineral aggregates, or rocks, water, air, etc. The *Animal* and *Vegetable Kingdoms* can be united under one head called the *Organic World*, and the *Mineral Kingdom* can be called the *Inorganic World*.

Our knowledge of these kingdoms has also its threefold classification: *Zoölogy* comprises our knowledge of the various forms of animal life; *Botany* relates to plant life; and *Mineralogy*, in its broadest sense, can be held to cover our knowledge of the inorganic world.

Botany and *Zoölogy* together are united under the broader term *Biology*, or the "Science of Life".

The inquiring student will find, however, that in

its more common acceptance the term **Mineralogy** is not used in its broadest or most universal sense, but is rather employed to comprise our knowledge of the simple minerals, when that term is used with a restricted meaning. If this limitation is applied, a **Mineral** may be defined as an inorganic body which has a more or less definite chemical composition and internal structure, and which, as a rule, tends to have a definite shape or form. *Mineral Chemistry* is the name of the science that relates to the chemical composition of the minerals; *Optical Mineralogy* is the name of the science which relates to the internal structure of minerals as shown by their effects upon light. The form that a mineral tends to assume is known as a **Crystal,** see Fig. 10, and our knowledge of these forms is named **Crystallography,** or the **Science of Crystals.**

As our present purpose is to enable a man to determine his minerals in the field and laboratory in the quickest and shortest way consistent with a fair degree of accuracy, it would not be necessary to devote time to Crystallography, if it were not that each mineral tends to have a more or less distinctive form or forms; and these forms, when sufficiently perfect for use, furnish us with the best, quickest, and surest means of determining a mineral. In many cases a mere glance is sufficient.

A **Mineral**, when it shows its crystallographic form, is seen to be bound by faces or planes; hence a **Crystal** can be defined as a body bounded by plane surfaces. See Fig. 9. Although theoretically the planes of a crystal are perfect and of equal size, yet in point of fact this is not generally true: first, because of the interference with one another of the adjacent crystals; and secondly, because of the necessity that each one should be implanted or should rest on something during its process of growth. By these and other causes the natural development of the planes of the crystal is hindered, and their outlines are distorted; some of the planes may even be totally suppressed. Thus the crystal planes are by no means constant in outline, size, or area, but they are closely, if not entirely, constant in their inclination to one another—that is, in the angles that each plane forms with those adjacent to it. See Figs. 12–27. The variations of these angles are so slight that rarely can they be detected except through accurate instrumental work. The ordinary work of a prospector or a student, who does not desire to be a professional Mineralogist, but rather to be able to determine his minerals in the shortest way consistent with a fair degree of accuracy, is such, that for all practical purposes the angles of any mineral species may be considered to be always identical.

Our method of locating a point upon a crystal may

be compared with the method commonly used in locating any point upon the earth's surface. In the latter the exact distance from a certain datum or reference point is determined, and the precise compass direction obtained. Thus one uses the distance measured along a certain line and the angle which that line makes with the meridian of that datum point. This is accurate enough for most local purposes and becomes more exact as one approaches the sea level. At the sea level one may also measure a distance east from a given point, say six miles, and then due north to the place to be located at a distance, say, of eight miles. It could then be stated that the point sought lay eight miles north and six miles east of the datum or reference locality. In case, however, the point to be located is not on the sea level, but on high land or a mountain, we would say that the locality under consideration was X miles south of the datum or given point A, Z miles west of it, and Y feet high above the sea level. This gives the exact position of the point which is to be located on the mountain. From this illustration one can see how points or bodies are located in space with reference to a chosen point by means of three lines at right angles to one another, or by means of the same or a greater number of lines placed at oblique angles or partially at right angles to one another.

This system of determining points can also be used for locating a plane or any other object in space, such as a star or the plane of a crystal.

Our entire mathematical conception of Crystallography is based on finding the location of the crystal planes and the angles they form with one another with reference to a single datum point. Our purpose in this work is not to discuss the subject mathematically, but merely to use such mathematical or space conceptions as will give us an idea of the relative position of different planes to the chosen datum point.

Returning to our idea of referring the location of any point to three or more lines and the angles that they make with one another, we find that there are practically six different methods or systems needed for the purpose of locating the different actual sets of planes found in nature upon the various minerals.

To apply these principles, first, select a certain datum point which is the point forming the theoretical or geometrical centre of the crystals. This centre is not the actual centre of gravity of most crystals, but the geometrical centre that would exist if the crystal were absolutely perfect, or if we conceive the planes so placed as to make it absolutely faultless. While this conception may appear difficult of attainment, yet with a little attention and thought it will be found very easy and simple. Secondly, from the above

chosen point draw lines of indefinite length, which form any angles whatsoever with one another, and we shall, by means of the datum point and of the three or four lines chosen and their angles of intersection, obtain data that will enable us to name the crystallographic forms. The above lines or directions are called **Axes.**

The process of learning to name the forms is simple and easy if one employs care and judgment about it; and this naming is all that is required in ordinary field and laboratory work. The mathematical description, calculation and correct drawing of the crystallographic forms is another and much more difficult matter, requiring a thorough knowledge of the principles of Spherical Trigonometry or Analytic Geometry of Three Dimensions and practice in Projection Drawing. The recognition of the crystal forms will require on the part of a good student with a suitable supply of crystal models and natural crystals from 15 to 25 hours of study and laboratory practice, while the mathematical work will demand months and perhaps even years of time.

Our purpose in these pages is simply to enable the student to study and name the forms and to understand the ordinary use of the so-called crystallographic nomenclature, or the figures and letters commonly written on or about a crystal or mineral form, as drawn and given in our mineralogical books and papers.

In representing our three axes in a drawing (Fig. 7), we readily see that if three planes be drawn through the intersection of the lines at the point A, and extending along these lines, as shown in Fig. 7, the space is then divided into eight parts or **Octants**; for instance, the part formed by the planes meeting in the points A B C D E F H is an octant. In an octant the angles and axial distances may all be equal, or they may all be unequal, or there may be every possible variation between these limits.

In arranging our systems we start with all the angles in each octant unequal and all the axes unequal. In varying from this we change in each octant first the angles, leaving the axes unequal; then we vary the axes, leaving the angles equal. Our variations of angles and axes then are as follows:

1. **Triclinic System.** All angles are oblique and both angles and axes unequal. See Fig. 1.

2. **Monoclinic System.** One of the angles is oblique and two are right angles, but all the axes are of unequal length. See Fig. 2.

3. **Orthorhombic System.** All three angles are right angles, but all the axes remain unequal. See Fig. 3.

4. **Tetragonal System.** All the angles are right angles, but two axes are equal and one is unequal to the other two. See Fig. 4.

5. **Isometric System.** All three angles are equal, and the three axes are equal. See Fig. 5.

6. Hexagonal System. In the sixth case we depart, as a matter of convenience, from the three axes and use four. Three of the four axes are placed horizontally and form angles of sixty degrees with one another. The fourth axis is placed vertically and forms right angles with the horizontal axes. See Fig. 6.

CHAPTER II

THE TRICLINIC SYSTEM

THIS system derives its name from the Greek *Tris*, "thrice," and *Klino*, "to slope, slant, or incline against," the term referring to the three-fold inclination of the axes to one another. In this system the planes are arranged about a given point or theoretical centre, from which the axes radiate, all forming different oblique angles with one another in the same octant. See Fig. 1. Practically the distance along the lines and the angles between the lines are all unequal. The axes in Crystallography are, however, no more real things than are the poles of the earth, its axis, equator, meridians, or parallels. The axes are simply chosen directions or imaginary lines that will enable us to describe the crystal in the shortest and most convenient manner. It must, however, be remembered that the selection of the axes or directions in this system is an arbitrary thing; for no matter what directions may be chosen, still others remain available.

NOMENCLATURE

Having selected our axes and their directions, we may next define some of the terms that we must use if we desire to be in accord with other writers upon this subject. If we commence with any one plane upon the crystal, that plane must cut all three of these axes at some distance, or be parallel to one or two of them. In accordance with geometrical usage a plane parallel to a line is said to cut that line at infinity, a distance which, according to mathematical custom, is designated by the figure 8 laid upon its side or horizontally (∞), or by an *i*, the initial of *infinity*. In the Triclinic System, when we are studying a crystal or model, the form is so placed that one axis is more nearly vertical than the other two. Hence we speak of the first as the **Vertical Axis,** although such language is rarely accurate. See Y, Fig. 1. The other two axes are called **Lateral Axes.** See X and Z, Fig. 1.

Since in this system all the axes are of unequal length it is necessary to distinguish one lateral axis from the other. This is done by calling the shorter axis the **Brachy-Axis** or **Brachy-Diagonal** (Greek, *Brachys*, "short"), (see X, Fig. 1), and the longer axis the **Macro-Axis** or **Macro-Diagonal** (Greek, *Makros*, "long"), see Z, Fig. 1.

PINACOIDS

In naming any plane of a crystal in this system, we observe which one of the three possible relations it may hold to the three chosen axes: **1.** The plane may intersect all three axes. **2.** It may cut two axes and be parallel to the third axis. **3.** It may intersect one axis and be parallel to the other two. In the last case it is evident that but six such planes can exist in this system, each one cutting each end of the three axes. These planes are called **Pinacoids,** from the Greek, *Pinax,* "a plank or board," and *Eidos,* "shape or form" which in composition takes the form of *oid* and is translated "resembling, or like, or in the form of." The name refers to the position of each of these planes on the sides or ends of the crystal, just as a slice forming a plank or board may be taken from the side or sides of a mill log by a saw. See 010, Figs. 8–10. The simplest method of designating the pinacoids is to name them from the axis that each one cuts; but practice has partially varied that system, so that our nomenclature is as follows:

1. If a pinacoid cuts the vertical axis it is called a **Vertical Pinacoid**; or more commonly, since the crystals, when studied, are placed or allowed to rest on one vertical pinacoid, it is usually named a **Basal Pinacoid** or **Basal Plane.** See 001, Fig. 33.

2. In case a pinacoid intersects one lateral axis and

thus is parallel to the other one and the vertical axis, it is named from the lateral axis to which it is parallel. If parallel to the brachy-axis, it is a **Brachy-Pinacoid**, (see 010, Figs. 8–10 and 31–35); if parallel to the macro-axis, it is a **Macro-Pinacoid**. See 100, Figs. 32–35.

DOMES AND PRISMS

If the plane cuts two axes but is parallel to the third axis, it is a **Dome** or **Prism Plane.** The term dome is derived from the Latin word *domus*, "a house." This term is employed because, when two dome planes meet, they form an angle with each other similar to that of the "pitch roof" of a house. See $1\bar{1}0 \angle 111$, Figs. 9 and 10. The domes or dome planes are named from the axis to which they are parallel; as, for example, a **Brachy-Dome** is so named when it lies parallel to the brachy-axis, (see 021, Fig. 30, and 101 and 102, Fig. 34); and a **Macro-Dome Plane** is so called when the plane is parallel to the macro-axis. Thus we may call a dome, like a house set on end, parallel to the vertical axis, a **Vertical Dome**; but it is customary to name the vertical dome planes **Prismatic Planes**, and to confine the term *dome planes* to those planes parallel to one of the lateral axes. See 110, Figs. 29–35.

PYRAMIDS OR OCTAHEDRONS

Having disposed of the problem of naming two out

of the three possible series of planes in this system, we now come to the third or last series, or the **Pyramids.** To repeat, in the first possible case the planes might intersect one axis and be parallel to the other two, giving rise to the **Pinacoidal Planes**; in the second possible series, the planes might intersect two axes and be parallel to the third, giving rise to our **Dome** or **Prism Planes**; and in this third or last case, the planes may cut all three axes, forming **Pyramidal Planes.** See 111, Figs. 28–32, 34, and 35. These cases cover all possible arrangements of planes about the axes of the Triclinic System.

AXIAL MODELS

Models of the different axial systems will be found useful if not indispensable for the proper understanding of the systems. These can be made by having wires suitably cut, and soldered together at the proper angles; or we may thrust wires through cork, making as before the different systems. Then, by using a piece of cardboard or better a glass plate as a crystal plane we can see the relative position of the planes and the points where they proportionately cut the axes, or intersect their prolongation.

SIMILAR AXES, PLANES, EDGES, AND ANGLES

In any system of axes, one axis or semi-axis is considered **similar** to another when it has the same length

and the same inclination to the other axis or semi-axis. For example, we may note that in the Triclinic System none of the semi-axes are similar; but that in the Isometric System all the axes and semi-axes are similar. See Figs. 1–6.

Planes are said to be **similar** when the distance from the centre to the points at which they cut similar semi-axes are equal. See planes 111, $1\bar{1}1$, $11\bar{1}$ and $1\bar{1}\bar{1}$, Figs. 12, 15, 17, and 18.

One edge is said to be **similar** to another edge when both are formed by the intersection of two **similar** planes. See the octahedral edges in Fig. 12.

A solid or crystal angle is said to be **similar** to another crystal angle when both are formed by the same number of similar planes. See the octahedral solid angles in Fig. 12.

SYMMETRY

The question naturally arising first in the mind of any student is how he can ascertain whether the crystal or crystal model belongs to the Triclinic System or not. In order to make this fairly easy, attention is called here to symmetry. The meaning of symmetry as here used may be illustrated by reference to a well-proportioned or symmetrical man. In this case his right hand is similar to his left hand, and his right ear, eye, arm, leg, and foot will also be similar when

each is compared with the corresponding member on the left side of the body. The same illustration can be carried out if we take certain undivided parts of the body, as for instance, the nose. A plane exactly cutting the nose from top to bottom into two equal parts would have the right nostril similar to the left, *i. e.*, the right half of the nose would be similar to the left half. A like division of the mouth and tongue would show that the two parts of each are similar. If we undertake to divide the body of a man into two equal parts so that each half shall be symmetrical with the other half, a little observation and thought will show us that there is only one position in which such a plane can be passed directly through the body; *e. g.*, from the head to the feet, separating the skull, nose, mouth, thorax, etc., into two equal and symmetrical parts. The same thing can be done with many other animals, like the dog or cat. The symmetry in such cases is said to be bilateral, and the plane that will divide the object into two symmetrical halves is called a **Plane of Symmetry**. See plane ABCD, Fig. 9.

In the majority of the lower orders of animals and plants more than one plane—sometimes several, sometimes many—can be found that will divide the object into two equal and symmetrical parts. So, too, in our crystals, the number of planes of symmetry may vary in the different systems from none to nine; and

in some cases they are extremely important as distinguishing characteristics of the systems. Symmetry does not exist in the abnormal and distorted forms of man or of other animals or of minerals, although the normal forms may show perfect or approximately perfect symmetry.

It is a common mistake for a student to suppose that symmetry implies that one of the symmetrical halves can exactly replace the other half. This is not a requirement of symmetry. The left half of a man can not be put in the position of the right half and fill its place; the necessary requirement is that the opposite halves shall have the same members and be similar in form. In crystals it is requisite that the planes, edges, and angles should be similar for each half.

Again, it is necessary that the two halves be symmetrical when looked at from any position, so that the plane of symmetry, if prolonged, would bisect the nose, eyes, and mouth of the observer; yet there is no more common mistake on the part of the inexperienced student than to think that a crystal is symmetrical, if after bisecting it with a plane of symmetry, he can turn one half into some other position so that it will then stand symmetrical with the other half. The symmetry must show without any turning or twisting of the crystal. Certainly no one would ever think of making the two halves of a man symmetrical by turn-

ing one-half partly around; and, while not as obvious to the observer, it is equally absurd to turn one-half of the crystal partly around to make it symmetrical with the other half.

If ordinary observation will not determine for the student a plane of symmetry, he can ascertain whether or not any chosen plane is a plane of symmetry by holding the crystal or model in front of a mirror, with the supposed plane of symmetry exactly parallel to the face of the mirror. If then the reflection of the side of the crystal or model shown in the mirror is exactly like the side of the crystal next to the observer or farthest from the mirror, the plane in question is a plane of symmetry.

If we examine Figs. 8–11, we can see what a plane of symmetry means in those forms. In Figs. 8 and 9 the plane of symmetry is the plane formed by the rhomboid A B C D. In these figures it can be seen that this plane so divides the crystals that the planes *e*, *f* and *P* on one side are exactly matched by similar planes on the other side of the crystal. In Fig. 10 the six-sided plane A B C D H is the plane of symmetry, and it divides the crystal into two similar halves, in which the right-hand plane *f* matches the left-hand plane *f*, and so on. In the case of Fig. 11 the plane of symmetry is the rhomboid A B C D, which divides the plane *r* into two equal parts, and

has the right side planes *l* and *M* matched by similar planes on the left side.

Symmetry shows itself not only in planes of symmetry but also in **Axes** and in **Centres of Symmetry.** When any direction is selected as an axis and the crystal or model is revolved about that axis, if similar planes or angles show from time to time in the same position on the form during such revolutions, the selected direction is called an **Axis of Symmetry.**

If the crystals represented by Figs. 36–40 are revolved about the vertical axis, it will be noticed that in each case similar planes are presented six times to the observer. Because the same faces recur six times during one complete revolution, such an axis of symmetry is called an **Axis of Hexagonal Symmetry** (Greek, *Hex*, "six" and *Gonos*, "angle").

In the case of Figs. 8–11, a like revolution of the crystals, which they represent, about their vertical axis shows the recurrence of similar faces in but two positions; hence this symmetry is called an **Axis of Binary Symmetry** (Latin, *Binarius*, "consisting of two").

In Figs. 41–44, a similar revolution of the crystals, which they represent, would show four positions in which similar faces present themselves. This axis of symmetry is then an **Axis of Tetragonal Symmetry** (Greek, *Tetra*, "four").

Figs. 45–50 show, when the crystals they represent

are revolved about the vertical axis, an **Axis of Trigonal Symmetry** (Greek, *Tris*, "thrice").

Crystals can have only Axes of Binary, Trigonal, Tetragonal, and Hexagonal Symmetry.

When each face, angle, and edge of a crystal or crystal model has a similar face, angle, or edge repeated exactly on the opposite side of the crystal or model, the theoretical central point or axial centre of the crystal or model is a **Centre of Symmetry**. Or, in other words, whenever one-half of the crystal or model has every plane, angle, and edge repeated by a similar plane, angle, or edge on the opposite half, the centre of that form is a **Centre of Symmetry**. Thus Centres of Symmetry are shown in Figs. 28–35, as the centre of each crystal has on one side a face matched by a plane on the other side; the same fact can be noted concerning all the other faces, angles, and edges on the crystals which these figures represent.

DISTINGUISHING CHARACTERISTICS OF THE TRICLINIC CRYSTALS

It is hardly scientific to define anything by stating what it has not, but in many cases this method of description is the simplest. So here we may say that the Triclinic System is characterized by the fact that it has no plane of symmetry; that is, we can find, in crystals belonging to this system, no plane that will

divide the crystals into two equal and symmetrical parts. See Figs. 28–35.

The absence of any plane of symmetry, while characteristic of the Triclinic System, is not an absolute proof of it, since some of the forms in the other systems have also no plane of symmetry. These forms are so extremely rare in the case of minerals that they will occasion no trouble in the field, and it is only in the case of crystal models or in artificial crystals that any difficulty will occur.

All difficulties, however, will disappear if we remember that in the case of the other five systems all the forms that have no plane of symmetry do have one or more axes of symmetry, while all the Triclinic forms are destitute of any axis of symmetry as well as of any planes of symmetry. They can only have a centre of symmetry.

Again, if a Triclinic crystal is placed on its basal plane, it can readily be seen that the side planes form oblique angles with the basal plane. In fact, the obliquity of the planes to one another or the twisting of the forms, as if a box were taken by its corners and twisted out of shape, can usually be seen in whatever position the crystals are placed.

From the obliquity of the angles the crystals of the Triclinic System are quite apt to have wedge-shaped forms, although the wedges are twisted or skewed, and

not straight, as are the wedge-shaped forms in the other systems. See Figs. 28–35.

From the above characters:

1. Determine whether or not the crystal model belongs to the Triclinic System.

2. Determine where the three axes are to be placed. They must be so located as to fulfill the requirements of this system; that is, they must be of equal length and form oblique angles with one another. If these conditions are fulfilled, then it is best to locate each axis parallel to some plane or edge: the planes or edges chosen must hold the same relation to one another; *i. e.*, they must form oblique angles and be of unequal length. As a rule place the axes so as to have first, as many pinacoidal planes as possible, and next as many prism or dome planes as possible, but with the fewest possible pyramidal planes.

RULES FOR NAMING TRICLINIC PLANES

I. If any plane cuts one axis and is parallel to the other two, it is a **Pinacoid.** If it cuts the vertical axis, it is a **Basal** or **Vertical Pinacoid,** or a **Basal Plane**; if it intersects the brachy-axis, it is a **Macro-Pinacoid**; if it cuts the macro-axis, it is a **Brachy-Pinacoid.**

II. If any plane cuts two axes and is parallel to the third axis, it is a **Dome** or **Prism Plane,** and is named from the axis to which it is parallel: if it is parallel to

the vertical axis, it is a **Prism** or a **Vertical-Dome Plane**; if it is parallel to the brachy-axis, it is a **Brachy-Dome Plane**; if it is parallel to the macro-axis, it is a **Macro-Dome Plane.**

III. If a plane cut all three axes, it is a **Pyramidal** or **Octahedral Plane.**

FORMS

The term **Form** is employed in Crystallography to indicate the union of similar planes about crystallographic axes.

These planes may or may not inclose space. In the case of eight similar planes forming an octahedron, space is inclosed between the planes. Four similar dome planes, arranged parallel to the same axis, inclose space in the same way that a stove-pipe does, but the ends are open, and space can only be actually inclosed by the addition of two pinacoids, one at each end. In like manner, two pinacoids in the Tetragonal or Hexagonal Systems make a form, but they do not inclose space.

From the above, we can see that in Crystallography the term *form* frequently has a significance somewhat different from its ordinary meaning.

In Crystallography we have complete forms, half forms, and quarter forms; and to enable us better to understand the meaning of forms in Crystallography, it is necessary to define these three kinds of forms.

1. **Holohedral Forms** occur when we have a union of all the similar possible planes that can be arranged about the axes of any crystallographic system. See Fig. 12. The name comes from the combination of two Greek words, *Holos*, " whole, perfect or complete," and *Hedra*, " a seat of any kind like a chair, stool or bench, or a foundation or base." This makes a somewhat far-fetched translation, as the implication is that the seats or places are all filled, which in Crystallography is said to mean a form with all possible faces. When crystals have the entire number of similar possible faces, it is customary to call them **Holohedral Forms**; and it should be noted that these forms possess all the symmetry possible in any given crystallographic system; *i. e.*, they have all the planes, axes, and centres of symmetry possible in that system. Such crystals are said to have the highest symmetry. It should be noted that the highest symmetry in the Isometric System comprises nine planes of symmetry, three axes of tetragonal symmetry, four axes of trigonal symmetry, six axes of binary symmetry, and a centre of symmetry. See Figs. 12, 15, and 17. Again, the highest symmetry of the Orthorhombic System is expressed by three planes of symmetry, three axes of binary symmetry, and a centre of symmetry. See Fig. 51.

Further, the Triclinic System has no plane or axis of

symmetry, but only a centre of symmetry. See Figs. 28–35. When the subject of Crystallography is developed from the Isometric System and ends with the Triclinic, it begins with the highest possible symmetry and complexity, descending towards the lower and simpler forms. On the other hand, if the development begins with the Triclinic System, it commences with the simplest forms, or lowest symmetry, and ascends towards the highest and most complex forms.

2. Hemihedral Forms occur when we have a union of one-half of all the similar possible planes that can be arranged about the axes of any crystallographic system. Hence all such forms are called hemi-forms, from the Greek, *Hemisys*, "the half," which is ordinarily contracted in compound words to *Hemi* or "half."

In the Hemihedral Forms the symmetry is lower than in the Holohedral Forms; *i. e.*, there are fewer planes or axes of symmetry than in the Holohedral Forms. For example, one set of Hemihedral Forms in the Isometric System has three planes of symmetry, four axes of trigonal symmetry, three axes of binary symmetry, and a centre of symmetry. See Figs. 52 and 53.

In the Triclinic System it should be noticed that at the most only two planes in any case are alike, *i. e.*, have similar indices. So in the case of the Prisms

and Domes, instead of four similar sides, there **exist** only two, or one-half of the completed form; hence these forms are called **Hemi-Prisms** and **Hemi-Domes.**

3. **Tetartohedral Forms** occur when we have a union of one-fourth of all the similar possible planes that can be arranged about the axes of any crystallographic system. These forms are called **Tetartohedral Forms,** from the Greek, *Tetartos,* "the fourth part of any thing." In the Triclinic System the Pyramids or Octahedrons have only one quarter of the faces necessary to make a complete form; hence, instead of calling the faces Pyramids, it is correct to speak of them as **Tetarto-Pyramids.** See Figs. 28–32 and 111, Figs. 34 and 35.

The Tetartohedral Forms have a low order of symmetry, as shown in the planes, axes, or centres of symmetry; for example, in the Hexagonal System a tetartohedral form known as the Trigonal Trapezohedron has neither plane nor centre of symmetry, but has one axis of trigonal and three axes of binary symmetry. See Figs. 54 and 55.

SIMPLE AND COMPOUND CRYSTALS

A crystal is said to be **simple** when it is made up of the planes of one form only. See Figs. 7, 12, and 52–55; but it is called **compound** when it is composed of the planes of two or more different forms.

See Figs. 8–11, 15–18, and 28–51. Compound crystals comprise a large majority of crystals. Simple crystals are found in the Hexagonal and Isometric Systems more often than in any of the others; while the Triclinic and Monoclinic crystals are all compound, for no single form in these systems can inclose space. See Figs. 28 and 35.

In describing these forms we require some special terms. Occasionally the planes of the several forms that make the compound crystals are all equally developed; but in most cases the planes of one form are more conspicuous than are those of the others. The chief form is called the **Dominant Form** and secondary ones are called **Subordinate Forms.** See Fig. 17.

In describing a crystal or model, it is usual to select the most conspicuous form as the **Dominant Form,** and then to state that it is **modified** by such and such **Subordinate Forms,** naming the secondary forms one after the other, in the order of their prominence. For example, in Fig. 17 we say that the dominant form is an octahedron (111) modified, first, by the planes of a cube, (100), and, secondly, by the planes of a dodecahedron, (110).

In the union of the various forms that make up the completed crystal, the planes of one form take the place of the edges or solid angles of another form. In such a case we use the term **Replace** to indicate the re-

lation of the two forms. For example, in Fig. 17 the dominant form is an octahedron (111), the solid angles of which are **replaced** by the planes of a cube (100), and the edges of which are **replaced** by the planes of a dodecahedron (110). In the above example the dodecahedral planes, (110), make, on each of their sides, equal angles with the octahedral planes (111); in such cases we commonly say that the edge of the octahedron (111) has been **truncated.** In like manner, the cube plane (100) is equally inclined to the four adjacent faces of the octahedron (111). In this case we usually say that the solid angles of the octahedron (111) have been **truncated** by the planes of a cube (100). From this we may define **Truncation** of an edge as the **Replacement** of that edge by a plane equally inclined to the adjacent similar planes. The **Truncation** of a solid angle is the **Replacement** of that angle by a plane equally inclined to the adjacent similar planes. Figs. 56–58 show a form of replacement that is commonly distinguished by the special term **Bevelment.** In this we can see that the two replacing planes are unequally inclined on opposite sides to the two planes forming the replaced edge, but that the intersections of all the planes are parallel. In Fig. 58 the replaced edge was formed by the meeting of the two planes, *a* and *d*. This edge is now replaced by the planes *b* (310) and *c* (130). The plane *b*, for instance, inclines on the plane *a* (100) at the same angle

that the plane *c* does on the cube face *d* (010). Again, the plane *b* inclines to the cube face *d* at a different angle from its inclination upon the cube face *a*. The plane *c*, in like manner, inclines on the cube face *a* at a different angle from that which it makes on *c*. These opposite inclinations are equal in the two planes. If this were not so, the intersections could not be parallel. We say then that an edge is **Bevelled** when it is replaced by two planes which are unequally inclined on opposite sides to the two planes forming the replaced edge, but which have all their intersections parallel.

It needs to be noted that in studying a crystal composed of several forms, no attention is to be paid to the shape or size of the replacing planes. Their inclinations to the axes are the only points with which we are concerned.

READING CRYSTALLOGRAPHIC DRAWINGS

In order to express the relations of the different planes to one another upon a crystal and to enable one crystallographer to understand the work of another, without his writing out long and tedious descriptions, several systems of crystallographic shorthand have been proposed. Of these systems, the one that formerly prevailed amongst English-speaking people is the German system of Weiss, which was subsequently modified by Naumann, and later by

J. D. Dana, whose symbols are the simplest of the three. The present prevailing system of notation, or at least the one that will in time receive almost if not quite universal adoption, is the Whewell-Grassmann-Miller system as modified by Bravais. For the elementary conception of crystals the crystallographic system of Naumann is more easily understood by the student and is better from the observational standpoint; but for the work of the crystallographer the Miller notation or the Miller-Bravais system lends itself to easier calculations, and is superior from the the mathematical view-point.

The French have generally employed the Haüy notation as modified by Lévy and Des Cloizeaux, but for our purpose attention will be given only to the notations of Weiss, Naumann, Dana and Miller-Bravais. These notations have been modified by some later crystallographers, notably Groth.

It is now time to turn our attention to crystallographic symbols. The first to be considered are those belonging to the axial notations. See Fig. 1. In this system, where the three axes are all of different lengths, the shorter lateral semi-axis is designated by the italic letter $\breve{a}$, over which the printer's breve or short vowel mark (⏑) is placed to indicate that it is the shorter lateral semi-axis or brachy-semi-axis. In a similar manner the longer of the lateral semi-axes is

designated by the italic letter $\bar{b}$, over which the macron or printer's long vowel mark (–) is placed to indicate that this is the longer lateral semi-axis or macro-semi-axis.

The vertical semi-axis is designated by the italic letter $\dot{c}$, over which is erected a short vertical mark or perpendicular (ˈ) to indicate that this refers to the vertical semi-axis.

A plane, in crystallographic notation, is always designated by the distance from the centre to the point at which it intersects each axis. The beginner may think this a very difficult procedure, but in practice it is simple enough; for we deal only with the relative distances and have nothing at all to do with the absolute distances. If the axes are different, as they are in this system, we assume a unit of distance on each axis: the unit is not an inch or any other standard measure of length, but implies that if one plane cut the axis at unity or 1, another plane may also intersect this axis at $\frac{2}{3}$, $\frac{3}{4}$, 2, 3, 4, or any number of times that unit of distance.

If we had hundreds of crystal planes parallel to one another, they could all then be reduced to our unit of distance and thus considered as one. It is only when the planes vary in their intercepts upon the axes that they are considered as separate planes. If in any crystal a plane is selected as the standard, it will be

found that all other planes intercept the axes either with the same unit of distance or at some simple multiple or fraction of it, like $\frac{1}{2}$, $\frac{1}{3}$, $\frac{2}{3}$, $\frac{3}{4}$, $\frac{4}{3}$, $\frac{5}{3}$, $\frac{5}{4}$, 2, 3, 4, 5, 6, 7, 8, 9, and so on.

The intercepts of a plane upon the axes are known as the **Parameters**; or we may define the parameters as the relative distances from the chosen centre of the crystal to the point at which a plane intersects the the imaginary axes. The important thing about a crystal plane is its inclination to the axes. This inclination varies only when the parameters vary; for if the parameters of one plane are written $1\ \breve{a} : 3\ \ddot{\bar{b}} : 2\ \dot{c}$ and those of another plane written $4\ \breve{a} : 12\ \bar{b} : 8\ \dot{c}$, it becomes at once apparent that if we divide the second set of parameters by 4, they reduce to the same form as the first, and that therefore the inclinations of the two planes are identical and the planes are both the same. From this it follows that the parameters should always be reduced to their lowest terms or have no common divisor. It may further be noticed that the sizes of the planes have no significance in Crystallography.

To return to our laws for the nomenclature of planes in the Triclinic System: by noting the position where the Vertical Pinacoid or Basal Plane cuts each axis, and by writing the axes with the parameter figures, we can see at once that the parameters of this plane will

be as follows: $\infty \breve{a} : \infty \bar{b} : 1 \dot{c}$. Now the figure 1 before the $\dot{c}$ is superfluous, and the parameters can be written thus: $\infty \breve{a} : \infty \bar{b} : \dot{c}$. These symbols may be translated as follows: the plane in question cuts both lateral axes at infinity or is parallel to them, while it intersects the vertical axis at the unit of distance. Such a plane can only be a Vertical Pinacoid or Basal Plane. When the parameters are written as above, the notation is known as the Weiss system. Naumann abbreviated this form by writing the capital letter *P* and placing zero before it, as follows: 0 *P*. Dana further abbreviated by writing this plane as *0* or *c*. Miller employs the reciprocals of the Weiss parameters, calling them **Indices**; *e. g.*, in the above, the reciprocals are $\frac{1}{\infty} : \frac{1}{\infty} : \frac{1}{1} = 0 : 0 : 1$; or, as it is the custom to write the indices in the Miller system without colons, the indices are written as follows: 0 0 1.

In every case in the Miller system where any of the reciprocals are in the form of fractions, all the indices are multiplied by the smallest number that will reduce all these fractions to whole numbers. From this it follows that all the Miller indices are whole numbers, generally ranging from 0 to 6.

In following out the above notations our symbols for the Brachy-Pinacoid would be in the Weiss method: $\infty \breve{a} : \bar{b} : \infty \dot{c}$, modified by Naumann to $\infty \breve{P} \infty$, or $\infty P \breve{\infty}$, and by Dana to i–$\breve{i}$, or *a*. Miller's indices would be 0 1 0.

In the case of a prismatic plane the Weiss notation would be $\breve{a} : \bar{b} : \infty \dot{c}$, or $\breve{a} : -\bar{b} : \infty \dot{c}$, according as the plane cuts the axis $\bar{b}$ (Fig. 1) on the right or the left side. Naumann's modifications are as follows: $\infty P'$ for the first, and $\infty {'P}$ for the second. Both of these Dana abbreviates as I' or m, and $'I$ or M.*

In marking the directions on the axes, parameters taken on the lateral axes to the front and to the right side are considered positive, but those measured towards the back and to the left side are called negative. The direction taken on the vertical axis above the lateral axes is called positive, while that below is called negative. See Fig. 1.

The positive sign (+) is not usually given, for it is understood that unless the negative (—) sign is written, all the parameters are positive. In order to indicate the different positions relative to the axes, Naumann used the accent mark placed to the right or left above and to the right or left below, as follows: P', $'P$, $P_{,}$, $_{,}P$. See Fig. 28. Some employ the accent mark not about the P, but in the same relative position about the letters or infinity sign accompanying the P; as $mP \infty'$, or $'mP \infty$.

* Besides using the symbols of Naumann, Dana, or Miller to designate the planes upon a crystal, it is not uncommon to select letters with or without any system. In such instances the text is expected to explain the notation in each case. Figs. 28–35 illustrate some of the methods of notation in the Triclinic System.

In the Miller notation as now employed the *a* semi-axis is always given first, the *b* semi-axis second, and the *c* semi-axis third, using for the indices either known integers, or else employing in their places the letters *h* for the *a* semi-axis, *k* for the *b* semi-axis, and *l* for the *c* semi-axis. But whenever either the *h*, *k*, or *l* become equal in value to one of the others, then the same letter is used in both cases; as, *h h l*, or *h k k*. When all three letters have the same values, the indices reduce instantly from *h h h* to 1 1 1. Whenever the direction is taken negatively in the Miller indices, the negative sign is written above the letter, as $\bar{h}$.

If the student now understands the Weiss system of notation derived from the intercepts of each plane upon each axis, it is hoped that Figs. 28–35 and the following table adapted from the works of Bauerman, J. D. and E. S. Dana, Groth, Liebisch, Mallard, and others, will make the notations intelligible to him.

TABLE I

TRICLINIC FORMS AND NOTATIONS

Form.	Weiss.	Naumann.	Dana.	Miller.
Basal-Pinacoids.	$\infty\breve{a} : \infty\bar{b} : \dot{c}$	$0P$	O or c	001
Brachy-Pinacoids.	$\infty\breve{a} : \bar{b} : \infty\dot{c}$	$\infty\breve{P}\infty$	$i\text{-}\breve{i}$ or b	010
Macro-Pinacoids.	$\breve{a} : \infty\bar{b} : \infty\dot{c}$	$\infty\bar{P}\infty$	$i\text{-}\bar{i}$ or a	100
Hemi-Prisms.	$\breve{a} : \bar{b} : \infty\dot{c}$	$\infty P'$	I' or m	110
	$\breve{a} : -\bar{b} : \infty\dot{c}$	$\infty'P$	$'I$ or M	$1\bar{1}0$
	$\breve{a} : n\bar{b} : \infty\dot{c}$	$\infty\bar{P}'n$	$i\text{-}\bar{n}'$	$hk0$
	$\breve{a} : -n\bar{b} : \infty\dot{c}$	$\infty'\bar{P}n$	$'i\text{-}\bar{n}$	$h\bar{k}0$
	$n\breve{a} : \bar{b} : \infty\dot{c}$	$\infty\breve{P}'n$	$i\text{-}\breve{n}$	$hk0$
	$n\breve{a} : \bar{b} : \infty\dot{c}$	$\infty'\breve{P}n$	$i\text{-}\breve{n}$	$h\bar{k}0$
Hemi-Brachy-Domes.	$\infty\breve{a} : \bar{b} : m\dot{c}$	$m{,}\breve{P}'\infty$	$m\text{-}\breve{i}$	$0kl$
	$\infty\breve{a} : -\bar{b} : m\dot{c}$	$m'\breve{P}{,}\infty$	$m\text{-}\breve{i}$	$0\bar{k}l$
Hemi-Macro-Domes.	$\breve{a} : \infty\bar{b} : m\dot{c}$	$m'\bar{P}'\infty$	$'m\text{-}\bar{i}'$	$h0l$
	$-\breve{a} : \infty\bar{b} : m\dot{c}$	$m{,}\bar{P}{,}\infty$	${,}m\text{-}\bar{i}{,}$	$\bar{h}0l$
Tetarto-Pyramids.	$\breve{a} : \bar{b} : \dot{c}$	P'	1	111
	$\breve{a} : \bar{b}' : \dot{c}$	$'P$	1	$1\bar{1}1$
	$\breve{a} : \bar{b} : \dot{c}'$	$P{,}$	1	$11\bar{1}$
	$\breve{a} : \bar{b}' : \dot{c}'$	${,}P$	1	$1\bar{1}\bar{1}$
	$\breve{a} : \bar{b} : m\dot{c}$	mP'	m'	hhl
	$-\breve{a} : \bar{b} : m\dot{c}$	$m{,}P$	${,}m$	$\bar{h}hl$
	$-\breve{a} : -\bar{b} : m\dot{c}$	$mP{,}$	$m{,}$	$\bar{h}\bar{h}l$
	$\breve{a} : -\bar{b} : m\dot{c}$	$m'P$	$'m$	$h\bar{h}l$
	$\breve{a} : n\bar{b} : m\dot{c}$	$m\bar{P}'n$	$m\text{-}\bar{n}'$	hkl
	$-\breve{a} : n\bar{b} : m\dot{c}$	$m{,}\bar{P}n$	${,}m\text{-}\bar{n}$	$\bar{h}kl$
	$-\breve{a} : n\bar{b} : m\dot{c}$	$m\bar{P}{,}n$	$m\text{-}\bar{n}{,}$	$\bar{h}\bar{k}l$
	$\breve{a} : -n\bar{b} : m\dot{c}$	$m{,}\bar{P}n$	$'m\text{-}\bar{n}$	$h\bar{k}l$
	$n\breve{a} : \bar{b} : m\dot{c}$	$m\breve{P}'n$	$m\text{-}\breve{n}'$	hkl
	$-n\breve{a} : \bar{b} : m\dot{c}$	$m{,}\breve{P}n$	${,}m\text{-}\breve{n}$	$\bar{h}kl$
	$-n\breve{a} : \bar{b} : m\dot{c}$	$m\breve{P}{,}n$	$m\text{-}\breve{n}{,}$	$\bar{h}\bar{k}l$
	$n\breve{a} : -\bar{b} : m\dot{c}$	$m'\breve{P}n$	$'m\text{-}\breve{n}$	$h\bar{k}l$

HEMIHEDRAL AND TETARTOHEDRAL NOTATIONS

The previous account of the notations particularly applies to the holohedral forms. The majority of crystallographers, however, indicate the hemihedral forms by writing $\frac{1}{2}$ in connection with the symbols, thus: $\frac{1}{2}$ $(\breve{a} : \infty \bar{b} : m\dot{c})$, or $\frac{m' P' \infty}{2}$, etc. For the tetartohedral forms the $\frac{1}{4}$ is written in the same way: $\frac{1}{4}$ $(\breve{a} : \bar{b} : m\dot{c})$, or $\frac{mP}{4}$. Sometimes the forms are considered *positive* and *negative*, or *right-handed* and *left-handed*. These conditions are indicated by writing + or —, or ± before the symbols, or by writing *r* or *l* for right or left before or after the symbols.

More use is made of this method of writing the symbols of the hemi- and tetarto-hedral forms in the Isometric and Hexagonal Systems than in any of the others. Very few writers, however, employ any method of notation to distinguish the half or quarter forms in the Triclinic System. In that system all the prisms and domes are hemihedral and all the pyramids are tetartohedral forms; hence it follows that any plane, whose symbol indicates that it is a dome or prism in this system, must belong to the half forms. In like manner, if the symbol of any face denotes that it is pyramidal, it must belong to the quarter forms. Therefore, it is considered that any special distinctive half or quarter form marks are unnecessary.

A few writers distinguish the partial forms in the Monoclinic System, but the majority do not use any of the characteristic fractions. These fractions are used chiefly in the other four systems, of which the Hexagonal and Isometric Systems, as before indicated, afford the majority of examples.

In the Miller System of notation the symbols, like $h\ k\ l$, stand for individual faces. Sometimes these are placed in ( ), as $(h\ k\ l)$, When they are united to make a *form*, the symbols of the plane have a brace { } written before and after them, as $\{h\ k\ l\}$.

The hemihedral and tetartohedral forms are indicated by writing some letter of the Greek alphabet before the symbol of the face or form ; *e. g.*, κ for hemihedral inclined faces and π for hemihedral parallel faces; $\kappa\ \{1\ 1\ 1\}$ and $\pi\ \{h\ k\ o\}$.

The more recent crystallographers have largely discarded the use of the terms *holohedral, hemihedral,* and *tetartohedral,* and prefer to consider that the six crystallographic systems are divided into thirty-two groups distinguished by their differences in symmetry. It is here preferred to retain the use of the above terms, because it is thought that, for the present at least, they offer the fewest difficulties to the student who studies crystallography simply as an aid in the practical field determination of minerals.

Since the parameters of a plane belonging to a half

or quarter form are exactly the same as they are when this plane is a constituent part of a holohedral form, there is in our common determinative work no inherent need of distinguishing the planes of the different partial forms from the entire forms.

They have to be distinguished when drawings are to be made, or when an exact idea of the *form* of the crystal is to be conveyed. For much of the determinative work the special separation into holohedral, or hemihedral, or tetartohedral forms is not required. Circumstances and particular conditions will determine when the special separation is desirable.

DIRECTIONS FOR STUDYING TRICLINIC CRYSTALS

1. Prove that the crystal or model is triclinic.

2. Locate the axes as previously directed.

3. Note the dominant and modifying forms.

4. In giving the forms say that the dominant form is ——— (naming the form); modified by ——— (naming the next important subordinate form); and so on, until all the forms have been given.

5. Select and name the pinacoids by the rule.

6. Select and name the dome and prism planes by the rule.

7. Select and name the pyramidal or octahedral planes by the rule. In naming the above planes, give, first, all those on the dominant form, and, secondly, all

the faces on each secondary form in order of the precedence of those forms.

8. In naming the forms state whether they are holohedral, hemihedral, or tetartohedral. To do this remember that if all the similar planes of any form are present, that form is holohedral; if one-half of all the similar planes are present, the form is hemihedral; and if only one-fourth of all the similar planes are present the form is tetartohedral.

9. Locate the planes, axes, and centres of symmetry, if there are any.

10. It is to be noted that a *crystal form* may have as many domes or prisms and octahedrons as there are different positions in which planes making these *forms* can intersect the axes without becoming parallel to any other plane; but in practice it is found that usually there are but few *forms* of any special class (pyramid, or dome, or prism) united in the same *compound form.*

CHAPTER III

THE MONOCLINIC SYSTEM

THIS system derives its name from the Greek word *Monos*, "one" and *Klino*, "to incline or lean against," from the inclination of one axis to the other two. In this system the axes are three in number and are unequal in length; because it is found that the simplest variation from the Triclinic System is to require that two of the axes be at right angles to each other, but form oblique angles with the other one.

SYMMETRY

Before we enter upon a fuller discussion of these forms, it is best to look at the plane of symmetry in the Monoclinic System. In this system an examination of the crystals shows that there is one direction, and only one, in which, if a plane be passed through the crystal, it will make a division into two equal and symmetrical halves. This single plane of symmetry occurs only in the Monoclinic System, with but three exceptions in other systems. See Figs. 198 and 199.

The exceptions can be distinguished by the fact that

the Monoclinic System has in the normal forms an axis of binary symmetry only, while the three exceptions have, respectively, axes of trigonal, tetragonal, and hexagonal symmetry. It should be particularly noted that the axis of binary symmetry in the Monoclinic System is perpendicular to the plane of symmetry. In this system the normal forms have a centre of symmetry. See Figs. 8–11 and 59–86.

NOMENCLATURE

In the Monoclinic System it is customary to locate the plane of symmetry first and the axis of symmetry next.

As a rule, a Monoclinic crystal placed on end will rest on one of two parallel planes or edges, and the shortest line joining them will be the vertical axis. See Figs. 9–11, 60, 64, 71, 78, and 83.

Having ascertained the plane and the axis of symmetry, place the crystal on its base or basal edge, and consider an axis to lie in that plane of symmetry, and to be drawn from the base parallel to the side planes and edges. As before stated, this axis is called the **Vertical Axis**. See $\dot{c}$, Figs. 2, 60, and 64. Of the other two axes one must be coincident with the axis of binary symmetry and therefore perpendicular to the plane of symmetry. The other axis must lie in the plane of symmetry and must be drawn, as a rule,

parallel to the base or basal edge. Both these axes are called **Lateral Axes.** The one that is perpendicular to the plane of symmetry is named the **Ortho-Axis** (see $\bar{b}$, Figs. 2, 60, and 64) or the **Ortho-Diagonal** (Greek, *Orthos*, "in a straight or right line"); while the other lateral axis, or the one lying in the plane of symmetry, is called the **Clino-Axis** (see $\grave{a}$, Figs. 2, 60, and 64), or **Clino-Diagonal** (Greek, *Klino*, "to incline, or to make a slope or slant, or to lean against"). From these meanings the Ortho-Axis is often called the *Straight Axis* and the Clino-Axis the *Inclined* or *Oblique Axis.*

In this case, as in the preceding one, planes may intersect only one axis, or cut two axes, or intersect all three, giving us as before **Pinacoids, Domes** or **Prisms,** and **Pyramids** or **Octahedrons.**

In the naming of pinacoids in the Monoclinic System, their relations to the axes are used, as in the Triclinic System. As the Monoclinic lateral axes have different names from the Triclinic lateral axes, the nomenclature will, in that respect, vary in the two systems. From this it follows:

1. If a pinacoid cuts the vertical axis and is parallel to the two lateral axes, it is a **Vertical Pinacoid**; but it is generally called a **Basal Plane,** or a **Basal Pinacoid.** See 001, Figs. 59–63, 65–70, and 73–77. On the other hand, the lateral pinacoids are named

from the lateral axis to which they are parallel; as, for example, if a pinacoid intersects the ortho-axis and is parallel to the clino-axis, it is a **Clino-Pinacoid** (see 010, Figs. 61, 67–72, 74, 75, 77, and 81–86); if it cuts the clino-axis and is parallel to the ortho-axis, it is designated as an **Ortho-Pinacoid** (see 100, Figs. 59, 61, 62, 65, 68, 71, 72, 78, and 83).

2. The dome or prism planes are named from the axis to which they are parallel. Thus they are called **Clino-Dome Planes** if they are parallel to the clino-axis (see 011, Figs. 65, 70, 75, and 84); but they are named **Ortho-Dome Planes** if they are parallel to the ortho-axis (see 401, 102, Fig. 69; and 101, Figs. 65, 66, 70, and 79); and they are called **Vertical Dome Planes**, or more commonly **Prism Planes**, if they are parallel to the vertical axis (see 110, Figs. 59, 60, 62, 63, 65–72, 74–77, and 82–86).

3. If a plane cuts all three axis, it is a **Pyramidal** or **Octahedral Plane**. See 111, Figs. 64, 68, 69, 71, 72, 77–83, 85, and 86.

RELATION OF PLANES TO THE AXES

To enable one to name the crystal planes in the easiest way, it is best, as a rule, to locate the axes parallel to the largest number of planes possible; *i. e.*, to make as many pinacoids, domes, and prisms as possible, and as few pyramids or octahedrons as possible.

DISTINGUISHING CHARACTERISTICS OF THE MONOCLINIC CRYSTALS

See whether or not the form belongs in the Monoclinic System, determining this, first, by the presence of one plane of symmetry and one binary axis of symmetry only, and next, by the fact that the edges and planes at the ends of the crystals make oblique angles with the edges and planes on the sides, so that when a model or perfect crystal is set on end, with an end plane or edge parallel to the table, it leans backwards, forming oblique angles with the table, but without any sidewise twist, as is the case with the Triclinic Crystals. See Figs. 28–35 for Triclinic Crystals, and Figs. 8–11, and 59–86 for Monoclinic Crystals.

RULES FOR NAMING MONOCLINIC PLANES

I. If a plane cuts one axis and is parallel to the other two, it is a **Pinacoid.** If it cuts the vertical axis, it is a **Basal** or **Vertical Pinacoïd,** or a **Basal Plane**; if it intersects the ortho-axis, it is a **Clino-Pinacoid**; if it cuts the clino-axis, it is an **Ortho-Pinacoid.**

II. If a plane cuts two axes and is parallel to the third axis, it is a **Dome** or **Prism Plane,** and is named from the axis to which it is parallel; if it is parallel to the vertical axis, it is a **Prism** or **Vertical Dome Plane**; if parallel to the clino-axis, it is a **Clino-Dome Plane**; if parallel to the ortho-axis, it is an **Ortho-Dome Plane,**

III. If a plane cuts three axes, it is a Pyramidal or Octahedral plane.

HOLOHEDRAL FORMS

The Holohedral Forms in this system are the prisms (vertical domes) and the clino-domes.

HEMIHEDRAL FORMS

The Hemihedral Forms in this system are the ortho-domes and pyramids or octahedrons; hence, all are properly called **Hemi-Ortho-Domes** and **Hemi-Pyramids** or **Hemi-Octahedrons.** They can be distinguished by their conformity to the laws for dome and pyramidal planes, and by the fact that they modify only one-half the similar planes upon the crystal. See Figs. 62, 63, 65 72, 75–77, and 79–86.

HEMIMORPHISM

The term **Hemimorphism** is employed to describe crystals whose opposite ends are unlike, *i. e.*, composed of different half-forms or of unlike planes (Greek, *Morphe*, "form" or "shape"). A requirement of true **Hemimorphism** is that these dissimilar planes or half-forms shall be at opposite ends of an axis of symmetry, which must also be a crystallographic axis. See Figs. 87 and 88.

No true hemimorphic forms occur amongst the minerals crystallizing in the Monoclinic System; but

there is one pseudo-hemimorphic form that needs to be considered here. It is the rare mineral clinohedrite ("inclined planes"), which is placed by itself in the Clinohedral Group. While this form resembles a hemimorphic form, it fails to be so classed because it lacks the essential characteristic of the hemimorphic forms, an axis of symmetry. This pseudo-hemimorphic form has neither axis nor centre of symmetry, but it does have a plane of symmetry.

COMPOUND FORMS

The compound forms of this system are comparatively simple, consisting of prisms, domes, and pinacoids; sometimes with hemi-pyramids, but more usually without them in the commoner forms. It is to be remembered that the holohedral and hemihedral forms are to be distinguished by the presence of all the possible similar planes for the holohedral forms, and by the presence of half the number of possible similar planes for the hemihedral forms. See Figs. 8–11, 59–86.

READING DRAWINGS OF MONOCLINIC CRYSTALS

In this system the letters used to designate the axes are the same as those employed in the Triclinic System; but for one of the lateral axes, the clino-axis, the distinguishing mark is the grave accent over the semi-axis letter, thus $\grave{a}$. Some authors, notably the Danas,

change the mark over the ortho-semi-axis letter b; *e. g.*, instead of writing $\bar{b}$, they write $\bar{b}$, using the sign $\perp$ to indicate the straight or ortho-axis or the perpendicular axis. Our axial letters and signs are then as follows:

Clino-Semi-Axis, $\grave{a}$.

Ortho-Semi-Axis, $\bar{b}$ or $\overset{\perp}{b}$.

Vertical Semi-Axis, $\dot{c}$.

Practically, then, the notation in the Monoclinic System will be similar to that of the Triclinic System, the variations being due to the different positions of the axes. The positive and negative signs for the parameters and indices are used as in the Triclinic System. See Figs. 2, 60, and 64.

Thus, in the Weiss notation, the symbols of the Vertical Pinacoid or Basal Plane are $\infty \grave{a} : \infty \bar{b} : \dot{c}$. This is abbreviated in the Naumann system as $0\ P$; in Dana's as O; and in Miller's as 0 0 1. See Fig. 61.

In the Naumann symbols the clino-axis or ortho-axis is marked either by this $P^{\backprime}$ or by $\bar{P}$; some, however, place the axial mark over the letters or the infinity symbol that accompanies the P, as $\infty P\grave{n}$ or $\infty P \bar{n}$, while others omit the marks. Table II, giving the Weiss, Naumann, Dana and Miller symbols, it is hoped, will make the different systems of symbols sufficiently clear to the student, especially if he will study Figs. 8–11 and 59–86.

As previously stated, only a very few crystallographers distinguish by symbols the hemihedral forms in the Monoclinic System, which has no tetartohedral forms amongst the minerals.

TABLE II

MONOCLINIC FORMS AND NOTATIONS

Form.	Weiss.	Naumann.	Dana.	Miller.
Basal Pinacoids.	$\infty \grave{a} : \infty \bar{b} : \dot{c}$	$0P$	O or c	001
Clino-Pinacoids.	$\infty \grave{a} : \bar{b} : \infty \dot{c}$	$\infty P \grave{\infty}$	$i\text{-}\grave{i}$ or b	010
Ortho-Pinacoids.	$\grave{a} : \infty \bar{b} : \infty \dot{c}$	$\infty P \bar{\infty}$	$i\text{-}\bar{i}$ or a	100
Prisms.	$\grave{a} : \bar{b} : \infty \dot{c}$	∞P	I or m	110
	$n\grave{a} : \bar{b} : \infty \dot{c}$	$\infty P\grave{n}$	$i\text{-}\grave{n}$	$hk0$
	$\grave{a} : n\bar{b} : \infty \dot{c}$	$\infty P\bar{n}$	$i\text{-}\bar{n}$	$hk0$
Clinodomes.	$\infty \grave{a} : \bar{b} : m\dot{c}$	$mP\grave{\infty}$	$m\text{-}\grave{i}$	$0kl$
Hemi-Orthodomes.	$\grave{a} : \infty \bar{b} : m\dot{c}$	$-mP\bar{\infty}$	$-m\text{-}\bar{i}$	$h0l$
	$\grave{a} : \infty \bar{b} : -m\dot{c}$	$mP\bar{\infty}$	$m\text{-}\bar{i}$	$\bar{h}0l$
Hemi-Pyramids.	$\grave{a} : \bar{b} : -\dot{c}$	P	1	$\bar{1}11$
	$\grave{a} : \bar{b} : \dot{c}$	$-P$	-1	111
	$\grave{a} : \bar{b} : -m\dot{c}$	mP	m	$\bar{h}hl$
	$\grave{a} : \bar{b} : m\dot{c}$	$-mP$	$-m$	hhl
	$n\grave{a} : \bar{b} : -m\dot{c}$	$mP\grave{n}$	$m\text{-}\grave{n}$	$\bar{h}kl$
	$n\grave{a} : \bar{b} : m\dot{c}$	$-mP\grave{n}$	$-m\text{-}\grave{n}$	hkl
	$\grave{a} : n\bar{b} : -m\dot{c}$	$mP\bar{n}$	$m\text{-}\bar{n}$	$\bar{h}kl$
	$\grave{a} : n\bar{b} : m\dot{c}$	$-mP\bar{n}$	$-m\text{-}\bar{n}$	hkl

DIRECTIONS FOR STUDYING MONOCLINIC CRYSTALS

1. Prove that the crystal or model is Monoclinic.

2. Determine the plane and the axis of symmetry; remembering that a single extremely rare pseudo-hemimorphic (clinohedral) form alone, amongst the Monoclinic minerals, has no axis of symmetry.

3. Locate the axes, as previously directed.

4. Note the dominant and modifying forms in the order of their importance.

5. Select and name the planes of each form in the following order: pinacoids, prisms, domes, and pyramids.

6. Distinguish the holohedral, hemihedral, and pseudo-hemimorphic or clinohedral forms.

CHAPTER IV

THE ORTHORHOMBIC SYSTEM

THIS system derives its name from the Greek, *Orthos*, "straight" or "right," and *Rhombos*, "a rhomb," because its similar planes commonly form right rhombs.

Continuing to vary the axes and angles, we note that this system must have all its axial angles right angles, while the axes still remain of unequal length.

NOMENCLATURE

Since the axes are of unequal length, it is necessary to distinguish each semi-axis by distinctive names and letters. This is done by using the same nomenclature as in the Triclinic System: **Brachy-Semi-Axis,** $\breve{a}$; **Macro-Semi-Axis,** $\bar{b}$; and **Vertical-Semi-Axis,** $\dot{c}$, respectively. See Fig. 3.

As before, the planes may intersect one axis and be parallel to the other two, forming **Pinacoidal Planes** (see 100, 001, and 010, Figs. 87–94, 97, 101–104, 108, 109, 118, 120–122, 125–129, and 131–135); or they may cut two axes and be parallel to the third axis, making **Dome** and **Prism Planes** (see 110, 101, 011,

120, 210, 012, and 021, Figs. 87–104, 113, 115, 117–121, and 123–135); or they may intersect all three axes, forming **Pyramidal** or **Octahedral Planes** (see 111, Figs. 87, 88, 91, 92, 96, 97, 105–129 and 131–135).

In naming the above planes we proceed as we did in the Triclinic System, using the same nomenclature. The student is referred to that system for the method.

RELATION OF PLANES TO AXES

In this system, as in the preceding systems, we place the axes, as a rule, so that they are parallel to the greatest number of planes possible; *i. e.*, to make as many pinacoids and as many domes and prisms as possible, and as few pyramids as possible.

SYMMETRY

In this system the normal forms have three planes of symmetry coinciding in direction with the three axes of the system, and therefore at right angles to one another. See Figs. 3, 7, 51, and 87–135.

The normal orthorhombic forms further have three axes of binary symmetry which are coincident with the three unequal crystal axes.

In the Isometric System the Pyritohedron or Pentagonal Dodecahedron (see Figs. 52 and 53), and the Diploid or Dyakis-Dodecahedron (see Figs. 136 and 137), have also three planes of symmetry only, which

are at right angles to one another. These forms need not be mistaken for Orthorhombic crystals, since they are of equal dimensions along each plane of symmetry, while in the Orthorhombic forms the dimensions are unequal.

The above Isometric forms also have three axes of binary symmetry that are coincident with the equal crystal axes, and they further have four axes of trigonal symmetry.

In the Hexagonal System the rhombohedral (see (Figs. 138 and 139), and scalenohedral (see Figs. 140 and 141) forms have also three planes of symmetry, but these form angles of 60° with one another, and all extend in the same direction; *i. e.*, they lie in the plane of the vertical axis, instead of forming right angles with one another, as in the Orthorhombic System.

The Rhombohedron and Scalenohedron also have three axes of binary symmetry, but they all lie in the plane of the lateral axes. They also have a vertical axis of trigonal symmetry coincident with the vertical crystal axis. Further, the three lateral dimensions of the Hexagonal crystals are the same, but all the dimensions are unequal in the Orthorhombic forms; while the similar parts are three or some multiple of three in the Hexagonal System, and but two or four or some multiple of four in the Orthorhombic System.

DISTINGUISHING CHARACTERISTICS OF THE ORTHO-RHOMBIC CRYSTALS

1. Determine whether or not the crystal or crystal model belongs to the Orthorhombic System. This can easily be done by noting the three unequal dimensions of the crystal; by observing that these dimensions form right angles with one another; by noticing the presence in the normal forms of but three planes of symmetry arranged at right angles with one another and parallel to the three unequal directions shown on the crystal; by noting that the three axes of binary symmetry lie in the three planes of symmetry and coincide with the three crystal axes; and by observing that the similar parts at the ends, or on the sides of the crystal, are in twos or fours, but never in threes or any multiple of three.

2. Having determined that the crystal is orthorhombic, place it generally with its thinnest direction in a vertical position. In many cases this gives a basal plane or pinacoid for it to rest upon. Call the direction perpendicular to the table the vertical axis; then imagine the planes of the ends prolonged until they meet or intersect. Consider then the longer of the two lateral directions thus formed the macro-axis, and the shorter will be the brachy-axis. It often happens that if we imagine the crystal planes to be prolonged until they meet one another, the apparently

shortest length of the crystal is the longest dimension. If the axes are properly selected in the normal forms, they will lie in the three planes of symmetry and will coincide with the three axes of binary symmetry.

RULES FOR NAMING ORTHORHOMBIC PLANES

I. A plane which intersects one axis and is parallel to the other two is a **Pinacoidal Plane**. If it cuts the vertical axis, it is called a **Basal Pinacoid** or **Basal Plane**. If it intersects the brachy-axis, it is an **Ortho-Pinacoid**. If it cuts the ortho-axis, it is a **Brachy-Pinacoid**.

II. If the plane intersects two axes and is parallel to the third axis, it is a **Dome** or **Prism Plane**. If this plane is parallel to the vertical axis, it is known as a **Vertical Dome Plane**, or more usually as a **Prism Plane**; if parallel to the clino-axis, it is a **Clino-Dome Plane**; if parallel to the ortho-axis, it is an **Ortho-Dome Plane**.

III. If the plane intersects all three axes, it is a **Pyramidal** or **Octahedral Plane**.

IV. In case the form has only half the full number of faces, give to that form the name of the hemihedral form that has the same parameters.

HOLOHEDRAL FORMS

Most of the common crystals of the Orthorhombic System are composed of holohedral forms. These

forms have, as previously stated, three planes of symmetry and three axes of binary symmetry.

HEMIHEDRAL FORMS

The hemi-domes and hemi-prisms are not very common in this system, and when they do occur they can be recognized by their modification of only one-half the similar parts of the dominant form.

The more commonly-occurring forms are hemi-pyramids, which produce wedge-shaped forms called **Sphenoids** (Greek, *Sphen*, "a wedge"). For purposes of distinction these forms are often called **Orthorhombic Sphenoids.** They are characterized by their wedge- or axe-shaped edges; and are distinguished from the wedge-shaped forms in the other systems by their three unequal dimensions, by the fact that their faces are scalene triangles, by the possession of three axes of binary symmetry, and by their lack of any plane or centre of symmetry. See Figs. 88 and 142–150. Figs. 88, 149, and 150 show how a sphenoid modifies the opposite ends of a crystal, producing a form that might be mistaken for a hemimorphic one.

The formation of the **Sphenoids** can be easily understood if we will take a simple pyramid and consider one-half of its planes obliterated (*i. e.*, alternate planes), and enlarge the other four alternate planes until they meet and make a complete form. Fig. 235 shows by

its blackened planes the faces to be obliterated. See Figs. 145 and 146. We can illustrate this for ourselves by pasting sheets of paper to the alternate faces of a model of a pyramid, and trimming the sheets until they join at their edges, making a completed form.

It is illustrated better by the glass models made in Germany, which show paper pyramids on the inside of the models with the alternate faces carried out in glass, until they meet, making glass sphenoids.

The above method of derivation of the sphenoid shows that another sphenoid can be formed if we carry out the planes which we before considered suppressed and then look upon the others as obliterated. We may designate these two sphenoids as positive and negative; or as they are related to each other as the right hand is to the left hand, it is usual to call the positive sphenoids right-handed and the negative ones left-handed.

HEMIMORPHIC FORMS

Fig. 87 represents a hemimorphic form of this system and shows distinctly the different planes modifying the opposite ends of the crystal.

In this system the hemimorphic forms have two dissimilar planes of symmetry and one axis of binary symmetry, but they are destitute of a centre of symmetry.

COMPOUND FORMS

The more usual compound forms in the Orthorhombic System are composed of pinacoids, prisms, and domes, sometimes without pyramids, but oftener with them, The holohedral forms are the most common, but these forms are not infrequently associated with hemihedral or hemimorphic forms. The hemihedral forms can be distinguished readily by the fact that they have half the number of possible similar planes. The hemimorphic forms can be determined by the fact that the planes at the opposite ends of a crystal axis (which is also an axis of symmetry) are dissimilar. See Figs. 87 135.

READING DRAWINGS OF ORTHORHOMBIC CRYSTALS

As previously mentioned the notation for the axes of the Orthorhombic System is as follows:

Brachy-Semi-Axis, $\breve{a}$.

Macro-Semi-Axis, $\bar{b}$.

Vertical Semi-Axis, $\dot{c}$.

See Fig. 3.

These symbols are considered positive or negative under the same rules as those given under the Triclinic System.

The notations in this system will then be almost identical with those of the Triclinic System. This fact leads to the belief that the Orthorhombic notations will not offer any difficulties to the student who has mastered the Triclinic notations.

The methods employed for distinguishing the right or positive sphenoids from the left or negative ones are shown sufficiently well in Table III, so that the student should have no difficulty in understanding the notations.

TABLE III

ORTHORHOMBIC FORMS AND NOTATIONS

Forms.	Weiss.	Naumann.	Dana.	Miller.
Basal Pinacoids.	$\infty\breve{a} : \infty\bar{b} : \dot{c}$	$0P$	O or c	001
Brachy-Pinacoids.	$\infty\breve{a} : \bar{b} : \infty\dot{c}$	$\infty\breve{P}\infty$	$i\text{-}\breve{i}$ or b	010
Macro-Pinacoids.	$\breve{a} : \infty\bar{b} : \infty\dot{c}$	$\infty\bar{P}\infty$	$i\text{-}\bar{i}$ or a	100
Prisms.	$\breve{a} : \bar{b} : \infty\dot{c}$ $n\breve{a} : \bar{b} : \infty\dot{c}$ $\breve{a} : n\bar{b} : \infty\dot{c}$	∞P $\infty\breve{P}n$ $\infty\bar{P}n$	I or m $i\text{-}\breve{n}$ $i\text{-}\bar{n}$	110 $hk0$ $hk0$
Brachy-Domes.	$\infty\breve{a} : b : m\dot{c}$	$m\breve{P}\infty$	$m\text{-}\breve{i}$	$0kl$
Macro-Domes.	$\breve{a} : \infty b : m\dot{c}$	$m\bar{P}\infty$	$m\text{-}\bar{i}$	$h0l$
Pyramids.	$\breve{a} : \bar{b} : \dot{c}$ $\breve{a} : \bar{b} : m\dot{c}$ $n\breve{a} : \bar{b} : m\dot{c}$ $\breve{a} : n\bar{b} : m\dot{c}$	P mP $m\breve{P}n$ $m\bar{P}n$	1 m $m\text{-}\breve{n}$ $m\text{-}\bar{n}$	111 hhl hkl hkl
Sphenoids.	$+$ or $r\,\frac{1}{2}(\breve{a} : \bar{b} : m\dot{c})$ $-$ or $l\,\frac{1}{2}(\breve{a} : \bar{b} : m\dot{c})$ $+$ or $r\,\frac{1}{2}(n\breve{a} : \bar{b} : m\dot{c})$ $-$ or $l\,\frac{1}{2}(n\breve{a} : \bar{b} : m\dot{c})$ $\pm$ or $\frac{r}{l}\,\frac{1}{2}(\breve{a} : n\bar{b} : m\dot{c})$	$+$ or $r\,\frac{mP}{2}$ $-$ or $l\,\frac{mP}{2}$ $+$ or $r\,\frac{m\breve{P}n}{2}$ $-$ or $l\,\frac{m\breve{P}n}{2}$ $\pm$ or $\frac{r}{l}\,\frac{m\bar{P}n}{2}$	$+$ or $r\,\frac{m}{2}$ $-$ or $l\,\frac{m}{2}$ $+$ or $r\,\frac{m\text{-}\breve{n}}{2}$ $-$ or $l\,\frac{m\text{-}\breve{n}}{2}$ $\pm$ or $\frac{r}{l}\,\frac{m\text{-}\bar{n}}{2}$	$\kappa\{hhl\}$ $\kappa\{h\bar{h}l\}$ $\kappa\{hkl\}$ $\kappa\{h\bar{k}l\}$ $\overset{+}{\kappa\{h\bar{k}l\}}$

DIRECTIONS FOR STUDYING ORTHORHOMBIC CRYSTALS

1. Prove that the crystal or model is orthorhombic.

2. Locate the axes, as previously directed.

3. Note the dominant and modifying forms in the order of their importance.

4. Select and name the planes of each form in the following order: pinacoids, prisms, domes, and pyramids.

5. Distinguish the holohedral, hemihedral, and hemimorphic forms, designating the sphenoids as such.

6. Locate the planes, axes, and centres of symmetry.

CHAPTER V

THE TETRAGONAL SYSTEM

In the next variation that leads to the formation of another system all the angles are right angles, but two of the axes are equal, and the third one is unequal in length to the other two.

The only requirement is that this third axis must be either longer or shorter than the other two and must be perpendicular to them. This variable axis is always selected as the **Vertical Axis**. The other two axes, also lying so as to make right angles with each other, as well as with the Vertical Axis, are called **Lateral Axes**. See Figs. 4 and 162.

NOMENCLATURE

In this system the nomenclature differs somewhat from that followed in the three preceding systems, becoming more complicated.

1. If a plane cuts the vertical axis and is parallel to the lateral axes, it is called a **Basal Pinacoid** or **Basal Plane**. See Figs. 147–149. There can be but two such planes on any crystal.

II. Of lateral planes parallel to the vertical axis three cases may occur:

1. The plane may cut both lateral axes equally, giving rise to a **Primary** or **Direct Prism Plane,** frequently called a **Prismatic Plane of the First Order.** See 110, Figs. 147, 150, and 157.

2. If the before-mentioned plane cuts only one lateral axis and is parallel to the other, it is known as a **Secondary** or **Inverse Prism Plane,** or as a **Prismatic Plane of the Second Order.** See 100 and 010, Figs. 152, 153, and 156–159, 174, 183, 188, and 190.

3. If the aforesaid plane cuts the two lateral axes at unequal distances, it is called a **Ditetragonal Prism Plane.** See $h\ k\ 0$, Figs. 160, 161, and 189; and 320, Fig. 190.

III. Again, if a plane cuts the vertical axis and intersects one or both lateral axes, it is called a **Pyramidal or Octahedral Plane.** Of Pyramidal Planes there may also be three cases:

1. If the plane in question cuts both lateral axes equally, it is known as a **Primary** or **Direct Pyramidal** or **Octahedral Plane,** or as a **Pyramidal Plane of the First Order.** See 111, Figs. 154, 155, 157, 159, 162, 164, 166–183, and 185–191.

2. If it cuts only one lateral axis and is parallel to the other, it is known as a **Secondary** or **Inverse Pyramidal Plane,** or as a **Pyramidal Plane of the Second**

Order. See 101, 011, and *h* 0 *l*, Figs. 156, 163, 165, and 175–182.

3. If it cuts both lateral axes at unequal distances, it is called a **Ditetragonal Pyramidal Plane**, or a **Zirconoidal Plane**, or a **Dioctahedral Plane**. See *h k l*, Figs. 160 and 184–186; 313, Figs. 187 and 188; and 321, Fig. 191.

RELATIONS OF THE PLANES TO THE AXES

As in the preceding system, the axes are to be located so as to have upon the crystal as many pinacoids and prisms as possible, with the fewest possible pyramids.

DISTINGUISHING CHARACTERISTICS OF TETRAGONAL CRYSTALS

Crystals that belong in this system are generally distinguished by the possession of two equal extensions and one unequal; by the fact that the opposite ends of the unequal extension are similar; and by the further fact that the planes at the ends of the unequal extension are commonly in twos, fours, or eights; or that the vertical axis (the axis of unequal extension) is coincident with an axis of binary or tetragonal symmetry.

RULES FOR NAMING TETRAGONAL PLANES

I. Any plane parallel to both the lateral axes is a

Pínacoid, and is called a **Basal Pinacoid** or a **Basal Plane.**

II. Any plane which cuts one or more lateral axes and is parallel to the vertical axis is a **Prismatic Plane.** If it intersects both lateral axes equally, it is a **Primary** or **Direct Prismatic Plane,** or a **Prismatic Plane of the First Order**; if it intersects one lateral axis but is parallel to the other, it is a **Secondary** or **Inverse Prismatic Plane,** or a **Prismatic Plane of the Second Order**; but if it cuts the lateral axes unequally, it is a **Ditetragonal** or **Dioctahedral Prismatic Plane.**

III. If the plane cuts all three axes, it is a **Pyramidal** or **Octahedral Plane.** If it cuts the two lateral axes equally, it is a **Primary** or **Direct Pyramidal** or **Direct Octahedral Plane,** or a **Pyramidal Plane of the First Order.** If it intersects one lateral axis and is parallel to the other, it is a **Secondary** or **Inverse Pyramidal** or **Inverse Octahedral Plane,** or a **Pyramidal Plane of the Second Order.** If it cuts the two lateral axes unequally, it is a **Ditetragonal Pyramidal Plane,** or a **Zirconoidal Plane,** or a **Dioctahedral Plane.**

IV. In case there are present only one-half as many faces as the complete form should have, give to the partial form the name that belongs to the hemihedral form having the same parameters.

HOLOHEDRAL FORMS

The majority of forms in this system are holohedral.

They are distinguished by the possession of five planes, five axes, and one centre of symmetry.

Of the axes of symmetry, one is an axis of tetragonal symmetry and the four others are axes of binary symmetry.

Of the planes of symmetry one is passed midway between the opposite ends of the unequal extension, parallel to the lateral axes and bisecting the vertical axis. Two of the other planes of symmetry pass through the vertical axis and the two lateral ones. Two more planes of symmetry pass through the vertical axis in such a way as to form an angle of 45° with each of the lateral axes.

The axis of tetragonal symmetry joins the opposite ends of the unequal extension, and is coincident with the vertical axis.

Of the axes of binary symmetry, two are coincident with the lateral axes. The other two lie in the plane of the lateral axes, but form angles of 45° with them.

In the simple forms the **Primary** and **Secondary Tetragonal Prisms** are identical in appearance, and we can call such simple forms Primary or Secondary, as we chose. It is customary, however, to call such simple forms Primary, and place the lateral axes accordingly. When the forms are compound, then the position of the axes of the selected dominant form determines whether the subordinate prisms are Primary or Secondary.

The above can be said also for the Primary and Secondary Pyramids.

It is obvious that there can be as many Primary and Secondary Pyramids upon a single crystal as there can be different positions on the vertical axis at which planes can cut that axis—or we might say, theoretically, an infinite number; yet we find practically only one, two, or three, or, at most, a very few pyramids.

HEMIHEDRAL FORMS

The hemihedral forms of the Tetragonal System that are important to Mineralogists can conveniently be divided into two groups, the **Sphenoidal** and the **Pyramidal**; but for crystallographic reasons, attention needs to be called also to the **Trapezohedral Group.**

I. The **Sphenoidal Group** is characterized by the wedge-shape of its forms, by the equality of two of their dimensions, and by the inequality of the third dimension compared with the two others.

Attention is called to two special forms in this group, the **Sphenoid** and the **Tetragonal Scalenohedron.**

1. The **Sphenoid** in this system is similar to that in the Orthorhombic System, except that two of the dimensions of the former are equal, while all three of the latter are unequal. The sphenoids are further distinguished by the fact that their four faces are

composed of isosceles triangles, while those of the Orthorhombic sphenoids are composed of scalene triangles. See Figs. 192–195.

As in the Orthorhombic System, we can consider these forms to have been produced by the obliteration of four alternate planes of the tetragonal or square pyramid, and by the prolongation of the other four alternate planes until they meet and make a complete form. See Fig. 236, whose blackened planes indicate the faces suppressed. For the purpose of distinction these sphenoids are often called **Tetragonal Sphenoids.** See Fig. 194.

2. The **Tetragonal Scalenohedron** can be considered to have been formed by the suppression of four alternate pairs of planes in the ditetragonal pyramid, and by the extension of the other four alternate pairs of planes, until they meet and make a complete form. See Fig. 237, in which the blackened planes indicate the planes suppressed. The resulting form has eight faces composed of scalene triangles, but the cutting edge of the wedge is broken, and is composed of two straight lines meeting at an angle. See Figs. 196 and 197. In the sphenoids the cutting edge is formed by a single straight line. See Figs. 192–194.

3. The symmetry in the Sphenoid and in the Tetragonal Scalenohedron is lower than that of the holohedral forms. In the **Sphenoidal Group** there are two

vertical planes of symmetry that form angles of 45° with the lateral axes. There are also three axes of binary symmetry coincident with the three crystallographic axes. There is no centre of symmetry. See Figs. 192–197.

II. The **Pyramidal Group** comprises only two distinct forms of importance in our work: the **Hemi-Ditetragonal Prisms,** or **Tertiary Prisms,** or **Prisms of the Third Order**; and the **Hemi-Ditetragonal Pyramids,** or **Tertiary Pyramids,** or **Pyramids of the Third Order.**

1. The **Hemi-Ditetragonal** or **Tertiary Prism** or **Prism of the Third Order** can be regarded as formed by the suppression of each alternate face of the ditetragonal prism and by the extension of the other four faces until they meet, forming a four-faced prism. This prism is found as a modifying form only. See Fig. 238, in which the shaded faces indicate the obliterated planes.

2. The **Hemi-Ditetragonal** or **Tertiary Pyramid** or **Pyramid of the Third Order** can be considered as formed by the suppression of alternate planes on the upper half of the ditetragonal pyramid, and a like suppression of the similar planes directly below. Then the set of eight corresponding faces are extended until they meet, completing the form and developing an eight-sided pyramid similar to the primary and secondary pyramids or to those of the first and second

order. See Fig. 239, whose shaded planes indicate the faces suppressed.

Both of the above forms can be distinguished by determining the parameters of the planes, and observing that the number of planes is one-half those required by the corresponding holohedral form. The **Tertiary Pyramid** or **Pyramid of the Third Order,** like the **Tertiary Prism** or **Prism of the Third Order,** never occurs except as a modifying form. If either of the above forms occurred alone as a simple form, it would be identical with a Primary or Secondary Prism or Pyramid. The different position of the lateral axes is the only distinguishing feature, and this can be observed only in compound forms. See Figs. 198 and 199.

Fig. 198 shows a cross-section of the primary prism or primary pyramid inscribed in a cross-section of a tertiary prism or pyramid. This figure illustrates the different positions of the lateral axes for the different prisms and pyramids when in compound forms, as shown in Fig. 199.

3. The symmetry of the Pyramidal Group is still lower than that of the **Sphenoidal Group.** The former has one plane of symmetry, a single axis of tetragonal symmetry, and a centre of symmetry. The plane of symmetry lies in the plane of the lateral axes and bisects the vertical axis. The axis of tetragonal sym-

metry is coincident with the vertical axis and therefore is perpendicular to the plane of symmetry.

III. The **Trapezohedral Group** or the **Tetragonal Trapezohedrons** are discussed here to some extent because they are common in the larger sets of crystal models. These forms are not known to occur in any natural minerals, but only in artificial crystallizations. They can be considered to be formed by the extension of the alternate planes of the ditetragonal pyramid above and below, until they meet, (see Fig. 184). This gives rise to two forms called respectively **Right-handed** (*r*) and **Left-handed** (*l*), or **Positive** and **Negative.** See Figs. 200 and 201.

The Trapezohedrons have four axes of binary symmetry lying in the plane of the lateral axes, and have one axis of tetragonal symmetry that coincides with the vertical axis.

COMPOUND FORMS

The common forms of the Tetragonal System are holohedral ones, which are sometimes combined with hemihedral forms. See Fig. 240. Of the hemihedral forms the sphenoids alone occur in crystals separated from other forms. See Figs. 192–194, 196, and 197.

READING DRAWINGS OF TETRAGONAL CRYSTALS

Since the lengths of the two lateral axes are the same, one letter will suffice to designate both semi-

lateral axes, a. For the vertical semi-axis the usual symbol is employed, c. The symbols of a simple prism in this system are, in the Weiss notation, $a : a : \infty \dot{c}$, or as it is very commonly written $a : a : \infty c$, with the omission of the vertical mark. Naumann's notation for this prism is ∞P, Dana's, I or m, and Miller's, 1 1 0.

The various notations are correlated for the forms in Table IV and, so far as may be, on the Figs. 41–44 and 151–201.

TABLE IV

TETRAGONAL FORMS AND NOTATIONS

Forms.	Weiss.	Naumann.	Dana.	Miller.
Basal Pinacoids.	$\infty a : \infty a : \dot{c}$	$0P$	O or c	001
Primary Prisms.	$a : a : \infty \dot{c}$	∞P	I or m	110
Secondary Prisms.	$a : \infty a : \infty \dot{c}$	$\infty P \infty$	i-i or a	100
Ditetragonal Prisms.	$a : na : \infty \dot{c}$	∞Pn	i-n	$hk0$
Primary Pyramids.	$a : a : \dot{c}$ $a : a : m\dot{c}$	P mP	1 m	111 hhl
Secondary Pyramids.	$a : \infty a : \dot{c}$ $a : \infty a : m\dot{c}$	$P\infty$ $mP\infty$	1-i m-i	101 $h0l$
Ditetragonal Pyramids.	$a : na : m\dot{c}$	mPn	m-n	hkl
Tetragonal Sphenoids.	$\frac{1}{2}(a : a : m\dot{c})$ $-\frac{1}{2}(a : a : m\dot{c})$	$\frac{mP}{2}$ $-\frac{mP}{2}$	$\frac{m}{2}$ $-\frac{m}{2}$	$\kappa\{hhl\}$ $\kappa\{h\bar{h}l\}$
Tetragonal Scalenohedrons.	$\frac{1}{2}(a : na : m\dot{c})$ $-\frac{1}{2}(a : na : m\dot{c})$	$\frac{mPn}{2}$ $-\frac{mPn}{2}$	$\frac{(m\text{-}n)}{2}$ $-\frac{(m\text{-}n)}{2}$	$\kappa\{hkl\}$ $\kappa\{h\bar{k}l\}$
Tertiary Prisms.	$\frac{1}{2}[a : na : \infty \dot{c}]$ $-\frac{1}{2}[a : na : \infty \dot{c}]$	$\left[\frac{\infty Pn}{2}\right]$ $-\left[\frac{\infty Pn}{2}\right]$	$\frac{i\text{-}n}{2}$ $-\frac{i\text{-}n}{2}$	$\pi\{hk0\}$ $\pi\{h\bar{k}0\}$
Tertiary Pyramids.	$\frac{1}{2}[a : na : m\dot{c}]$ $-\frac{1}{2}[a : na : m\dot{c}]$	$\left[\frac{mPn}{2}\right]$ $-\left[\frac{mPn}{2}\right]$	$\frac{[m\text{-}n]}{2}$ $-\frac{[m\text{-}n]}{2}$	$\pi\{hkl\}$ $\pi\{\bar{h}kl\}$
Tetragonal Trapezohedrons.	$\frac{1}{2}(a : na : m\dot{c})r$ $-\frac{1}{2}(a : na : m\dot{c})\,l$	$\frac{mPn}{2}\,r$ $-\frac{mPn}{2}\,l$	$\frac{m\text{-}n}{2}\,r$ $-\frac{m\text{-}n}{2}\,l$	$\tau\{hkl\}$ $\tau\{h\bar{k}l\}$

DIRECTIONS FOR STUDYING TETRAGONAL CRYSTALS

1. Prove that the crystal or model is Tetragonal.

2. Locate the axes, as previously directed.

3. Note the dominant and modifying forms in the order of their importance.

4. Select and name the planes of each form in the following order: pinacoids, prisms, domes, and pyramids.

5. Distinguish the holohedral and hemihedral forms, naming the sphenoids, scalenohedrons, tertiary prisms and pyramids, and the trapezohedrons when they occur.

6. Locate the planes, axes, and centres of symmetry.

CHAPTER VI

THE HEXAGONAL SYSTEM

In this system it is found best, as a matter of practical convenience, to depart from the custom followed in the other systems of using three axes, and to employ four. Of these four, three are taken as **Lateral Axes,** and are so placed that they form angles of 60° with one another. The fourth axis, like the Tetragonal vertical axis, is either longer or shorter than the lateral axes, and is perpendicular to them. This axis is called, as in the other systems, the **Vertical Axis.** See Fig. 6.

The **Hexagonal System** is considered in connection with the Tetragonal System, because it has one dimension that is either longer or shorter than its other dimensions, which are equal to one another; also because the end planes of the longer or shorter direction are similar to one another, but are unlike the planes on the sides. The most obvious difference in the forms is that the Tetragonal System has its parts in twos, fours, or eights (see Figs. 41–44 and 154–201), while the Hexagonal System has its parts in threes,

sixes, or some multiple of three. See Figs. 36–40, 45–50, 54, 55, 138–141, 202–234, and 240–324.

The symmetries of the holohedral forms in the two systems are similar, as the Tetragonal System has one horizontal and four vertical planes of symmetry (see Figs. 41–44, 155, 157–159, and 161–191), while the Hexagonal System has one horizontal and six vertical planes of symmetry (see Figs. 36–40, 203–208, 254–267, 315–319, and 321–323).

Some crystallographers, *e. g.*, Miller and Schrauf, employ three axes for this system, while others, *e. g.*, Groth, separate the Hexagonal System into two parts; one part retains the old name of the Hexagonal System and has, like it, four axes, while the other part is designated as the Rhombohedral or Trigonal System and has only three axes.

Liebisch uses the four axes for the complete system and divides it into two grand divisions according to the grade of the axis of symmetry which is coincident with the vertical axis. When the vertical axis is coincident with an axis of hexagonal symmetry, the forms are placed in the **Hexagonal Division.** When the vertical axis is coincident with an axis of trigonal symmetry, the forms are placed in the **Rhombohedral (Trigonal) Division.** The same divisions are made by the Danas and by Moses.

For the semi-axis in the Hexagonal System we use

in the Miller-Bravais notation the following indices (see Fig. 6): h for the a_1 semi-axis; $\bar{h}$ for the $-a_1$; k for the a_2; $\bar{k}$ for the $-a_2$; i for the a_3; $\bar{\imath}$ for the $-a_3$; l for the $\dot{c}$; and $\bar{l}$ for the $-\dot{c}$.

To repeat, the Miller-Bravais Indices, then, are $h\,k\,\bar{\imath}\,l$, and the modernized Weiss Parameters are $a_1 : a_2 : -a_3 : \dot{c}$, or, in a more general form, $na_1 : pa_2 : -a_3 : m\dot{c}$. It is, however, customary to omit the subscript figures, since the lateral semi-axes are all equal, and to write the notations as follows: $na : pa : -a : m\dot{c}$. The vertical mark is often omitted over the c, as it is in the Tetragonal System.

NOMENCLATURE

Owing to the employment of the four axes and to the diverse grades of symmetry, or to the numerous and important partial forms, the nomenclature in this system is more complicated than in the Tetragonal or even in the Isometric System. To a considerable extent the forms have names similar to those of the Tetragonal System.

RELATIONS OF PLANES TO AXES

As in the preceding system, the axes are placed so as to have as many pinacoidal and prismatic planes as possible, with the fewest possible pyramidal planes. This rule extends to all the partial as well as to the holohedral forms.

DISTINGUISHING CHARACTERISTICS OF HEXAGONAL CRYSTALS

The crystals of this system are generally distinguished by the possession of three equal extensions and one unequal; by the fact that the opposite ends of the unequal extension are similar; and by the further fact that the planes at the ends of the unequal extension are commonly in threes or sixes or some multiple of three; or, as previously stated, the vertical axis (the axis of unequal extension) is coincident with an axis of hexagonal or trigonal symmetry. See Figs. 36–40, 45–50, 54, 55, 138–141, 202–234, and 241–324.

PRINCIPAL FORMS OF THE HEXAGONAL SYSTEM

As a matter of convenience there is given below a summary of the principal forms of this system, or those which are described more fully later in the text.

I. **Holohedral Forms**:

1. Basal Pinacoid.
2. Primary Hexagonal Prism.
3. Secondary Hexagonal Prism.
4. Dihexagonal Prism.
5. Primary Hexagonal Pyramid.
6. Secondary Hexagonal Pyramid.
7. Dihexagonal Pyramid.

II. **Hemihedral Forms**:

- **A.** Rhombohedral Group:
  - **1.** Primary Rhombohedron:
    - **a.** Positive.
    - **b.** Negative.
  - **2.** Hexagonal Scalenohedron:
    - **a.** Positive.
    - **b.** Negative.
- **B.** Pyramidal Group:
  - **1.** Tertiary Hexagonal Prism:
    - **a.** Positive or Right-handed.
    - **b.** Negative or Left-handed.
  - **2.** Tertiary Hexagonal Pyramid:
    - **a.** Positive or Right-handed.
    - **b.** Negative or Left-handed.
- **C.** Trapezohedral Group:
  - **1.** Hexagonal Trapezohedron:
    - **a.** Positive or Right-handed.
    - **b.** Negative or Left-handed.
- **D.** Trigonal Group:
  - **1.** Ditrigonal Pyramid:
    - **a.** Positive.
    - **b.** Negative.

III. **Tetartohedral Forms**:

- **A.** Rhombohedral Group:
  - **1.** Secondary Rhombohedron:
    - **a.** Positive:

u. Right-handed.
w. Left-handed.

b. Negative:

x. Right-handed.
z. Left-handed.

2. Tertiary Rhombohedron:

a. Positive:

u. Right-handed.
w. Left-handed.

b. Negative:

x. Right-handed.
z. Left-handed.

B. Trapezohedral Group:

1. Secondary Trigonal Prism:

a. Positive or Right-handed.
b. Negative or Left-handed.

2. Ditrigonal Prism:

a. Positive or Right-handed.
b. Negative or Left-handed.

3. Secondary Trigonal Pyramid:

a. Positive:

u. Right-handed.
w. Left-handed.

b. Negative:

x. Right-handed.
z. Left-handed.

4. Trigonal Trapezohedron:

a. Positive:

u. Right-handed.

w. Left-handed.

b. Negative:

x. Right-handed.

z. Left-handed.

C. Trigonal Group:

1. Primary Trigonal Prism:

a. Positive.

b. Negative.

2. Tertiary Trigonal Prism:

a. Positive:

u. Right-handed.

w. Left-handed.

b. Negative:

x. Right-handed.

z. Left-handed.

3. Primary Trigonal Pyramid:

a. Positive.

b. Negative.

4. Tertiary Trigonal Pyramid:

a. Positive:

u. Right-handed.

w. Left-handed.

b. Negative:

x. Right-handed.

z. Left-handed.

IV. **Hemimorphic Forms**:

1. Iodyrite Type.
2. Nephelite Type.
3. Tourmaline Type.
4. Sodium-Periodate Type.

I. HOLOHEDRAL FORMS

In one prominent respect the Hexagonal System differs from the preceding systems: in the Hexagonal System the holohedral forms are less common and important than are the hemihedral forms.

Following as closely as practicable the nomenclature of the Tetragonal System, we find that the holohedral planes and their names are related to the axes as follows:

1. If the plane is parallel to the lateral axes, it is a **Pinacoid,** commonly called a **Basal Pinacoid** or a **Basal Plane.** Its symbol is 0 *P* or 0001. There can be but two such planes on a crystal, the same as in the Tetragonal System. See 0 *P* or 0001, Figs. 37–39, 205–207, 215, 216, 220, 221, 242, 246–248, 263, 269, 272, 275, 289, and 315–323.

2. A plane parallel to the vertical axis and to one of the lateral axes, and cutting the other two lateral axes at equal distances from the centre of the crystal, is known as a plane belonging to a **Primary Hexagonal Prism** or a **Hexagonal Prism of the First Order.** In this form the angles of the lateral edges are all

equal. See ∞P or $10\bar{1}0$, Figs. 36–38, 40, 49, 202, 205, 212–214, 217, 219, 254, 255, 283, 298, 302–304, 307–319, and 321–323. If a plane is parallel to the vertical axis, cuts one lateral axis at some unit of distance, and intersects the other two lateral axes at twice that unit of distance, it is said to be a plane belonging to a **Secondary Hexagonal Prism** or a **Hexagonal Prism of the Second Order**. As in the Primary Prism, the angles of the lateral edges are all equal. See $\infty P2$ or $11\bar{2}0$, Figs. 46, 50, 206, 212, 215, 216, 220, 278–280, 299, 318–320, 322, and 323. If the plane is parallel to the vertical axis, but cuts all three lateral axes at unequal distances, then the plane is said to belong to a **Dihexagonal Prism**. In this form the alternate angles of the lateral edges are unequal. See Figs. 207, 219, 242, 246, and 257.

3. If a plane cuts the vertical axis, is parallel to one lateral axis, and intersects the other two at equal distances, the plane belongs to a **Primary Hexagonal Pyramid** or a **Hexagonal Pyramid of the First Order.** In this form the lateral edges are straight and equal, while the edges running to the apices form equal angles. See $h0\bar{h}l$, $10\bar{1}1$, mP, and P, Figs. 36–39, 47, 202, 203, 212–214, 217–219, 254–266, 315, 316, 318, 319, and 321–323. If the plane cuts the vertical axis and intersects one lateral axis at a chosen unit of distance, and the other two lateral axes at twice that unit

of distance, it is a plane belonging to a **Secondary Hexagonal Pyramid** or a **Hexagonal Pyramid of the Second Order.** The edges and angles are the same as in the Primary Pyramid. See *P*2, 2*P*2, *mP*2, *hh*2*hl*, and $11\bar{2}2$, Figs. 37, 40, 204, 209, 212, 243, 249, 255, 258, 261, 267, 276, 306, 308, 317, 319, and 321–323. If the plane cuts the vertical axis and intersects all the lateral axes at unequal distances, it belongs to a **Dihexagonal Pyramid.** The lateral edges are horizontal and equal, but the alternate angles formed by the edges running to the apices are unequal. See $hk\bar{i}l$, *mPn*, $21\bar{3}3$, and $3P\frac{3}{2}$, Figs. 40, 208, 219, 229, 234, 241, 259, 262, 266, and 321.

4. The above statements apply to the holohedral forms. In case the plane is found to belong to a partial form, then the special name of the partial form having the same parameters should be used.

The **Primary Hexagonal Prism** and **Pyramid** possess cross-sections as shown in Fig. 202, which indicates the relation of the lateral axes to the planes.

When the **Secondary Hexagonal Prism** or **Pyramid** is in a simple form, its appearance is identical with that of the Primary Hexagonal Prism or Pyramid. We may call these simple forms either Primary or Secondary, as we prefer, although it is customary always to call the simple forms **Primary**, as in the case of the Tetragonal System. See Figs. 36–40, 202–

206, 212, 218, 243, 249, 254, 264, 268, 315–318, and 323.

When the forms are compound, then the position of the axes of the dominant form determines whether the subordinate forms are Primary or Secondary. See Figs. 36–40, 254–267, and 308–323.

As in the Tetragonal System, we can have as many Primary and Secondary Pyramids as we can have different points on the vertical axis. That is, we can have, theoretically, an indefinite number; practically we find but few on any crystal. See Figs. 36–40, 254–267, and 308–323.

A student naturally desires to know why, in the case of the **Secondary Prisms** and **Pyramids**, we state that the planes cut two lateral axes at twice the unit of distance at which it cuts the other one.

The reason is shown by a simple trigonometric operation. See Fig. 209. From Geometry we know that the side of a regular hexagon inscribed in a circle is equal to the radius of that circle. This makes the side (d) of the hexagon and the two radii (b and g) equal. Since, then, the triangle formed by the sides b, d, and s is an equilateral one, it follows according to Geometry that the angles are all equal. The sides b and d of the triangle are the semi-axes in a section of a primary hexagonal prism or pyramid. See Fig. 202. Therefore the angle b p d is an angle of 60°, and hence the

other two angles of the triangle are angles of 60°. From Trigonometry we learn that u r is the tangent of the angle b p d or 60°. Trigonometry also teaches us that Tan. $60° = \sqrt{3}$. From Geometry we know that $(pr)^2 = b^2 + (ur)^2$. Now b is the shorter axis or the smaller parameter of the secondary prism or pyramid; therefore, in Crystallography it is unity or 1; while u r is the tangent of 60° or $\sqrt{3}$. Hence by substituting these numbers our equation reads: $(pr)^2 = 1^2 + (\sqrt{3})^2$, or $pr = \sqrt{1+3} = \sqrt{4} = 2$. Now the 2 thus obtained is one of the longer parameters of the secondary prism or pyramid. From inspection of Fig. 209 it can be seen that both the longer parameters are the same; hence it follows that in the Weiss notation the parameters of a secondary prism would be $2a : -a : 2a : \infty c$, and those of a secondary pyramid would be $2a : -a : 2a : mc$.

The holohedral forms possess six vertical planes of symmetry: three are coincident with the vertical axis and the three lateral axes; the other three coincide with the vertical axis, but bisect the angles between the lateral axes. Further, there is one horizontal plane of symmetry which bisects the vertical axis and lies in the plane of the lateral axes.

Again, the holohedral forms have six horizontal axes of binary symmetry: three that bisect the angles between the lateral axes, and three that are coincident

with those crystal axes. These forms have also a vertical axis of hexagonal symmetry which is coincident with the vertical crystal axis, as well as a centre of symmetry.

II. HEMIHEDRAL FORMS

A. Rhombohedral Group. The distinctive forms in this group are two:

1. **The Rhombohedron.**
2. **The Scalenohedron.**

1. **The Rhombohedron** as a hemihedral form can be considered to be produced by the suppression of the alternate upper and lower planes of the primary hexagonal pyramid and by the extension of the other alternate planes until they meet one another so as to produce a complete form. See Figs. 218 and 233. In Fig. 218, if the shaded planes are the ones considered suppressed, the rhombohedron produced by the extension of the non-shaded planes until they meet is called a **Positive Rhombohedron.** See Fig. 139.

A rhombohedron is called *Positive* when one of its three upper rhombs stands face to face with the observer.

When the shaded parts of the primary hexagonal pyramid (Fig. 218) are the parts carried out until they meet, and the non-shaded parts are the parts obliterated, then the rhombohedron produced is known as a **Negative Rhombohedron.** See Fig. 138.

A rhombohedron is called *Negative* when one of the three upper edges is turned directly towards the observer; or in other words, when this edge lies in the plane of symmetry bisecting the observer.

Besides the six equal and similar rhombs that bound the rhombohedron, it possesses two kinds of edges and two kinds of solid angles. There are six similar **Terminal Edges,** three above and three below, which are marked in Figs. 138 and 139 by the letter A. The junction of each set of three terminal edges marks each end of the vertical axis. Again, there are six equal and similar **Lateral Edges,** which run zigzag about the crystal and which are designated by the letter B, in the same figures.

At each end of the vertical axis there is a solid angle formed by three equal plane angles. These two solid angles are designated on the figures by the letter C. Further, the rhombohedrons have six lateral solid angles, designated by the letter D. While these lateral angles are similar, they are not formed by the intersection of equal plane angles, but by either two obtuse angles and one acute angle, or by one obtuse angle and two acute angles. The angles measured over the lateral edges are all alike, but are different from the angles measured over the terminal edges. If the angle obtained by measuring over a terminal edge is added to the angle obtained by measuring over a lateral edge,

the sum of the two is 180°; or one is as much greater than a right angle as the other is less. Hence it is customary to place the rhombohedrons in two sections, **Acute** and **Obtuse.**

An **Acute Rhombohedron** is one whose equal angles measured over the terminal edges are each less than 90°. See Fig. 222.

An **Obtuse Rhombohedron** is one whose equal angles measured over the terminal edges are each greater than 90°. See Fig. 223.

It often happens that, upon a crystal, several different rhombohedrons occur, which have the same intercepts upon the lateral axes, but have different intercepts upon the vertical axis. In such a case one is selected as the **Principal** or **Fundamental Rhombohedron,** while the others are considered as **Subordinate Rhombohedrons.** See Figs. 45, 224–228, 270, 271, 275–277, 280, and 307–314.

Having selected the principal rhombohedron, we find that all rhombohedrons which have the same lateral parameters, but which have larger intercepts on the vertical axis, are acute rhombohedrons, but that if they have smaller intercepts on the vertical axis, they are obtuse rhombohedrons. See Figs. 224–227, 275–277, 280, and 286.

It is found that these rhombohedrons have this relation to one another: A positive rhombohedron will

truncate the terminal edges of the negative rhombohedron that has twice its parameter on the vertical axis. Again, a negative rhombohedron will truncate the terminal edges of the positive rhombohedron that has twice its parameter on the vertical axis. See Figs. 45, 225, and 228.

The vertical axis, as before stated, joins the trihedral solid angles, while the three lateral axes join the centres of the opposite lateral zigzag edges.

The rhombohedrons thus far described are often designated as **Primary Rhombohedrons** or as **Rhombohedrons of the First Order.**

2. The **Hexagonal Scalenohedron** as a hemihedral form of the Hexagonal System is regarded as being formed by the suppression of alternate pairs of adjacent planes above and alternate pairs of adjacent planes below; and by the extension of the remaining pairs of planes of the dihexagonal pyramid until they meet and form a complete figure. This is illustrated in Fig. 229, in which the extended faces are shaded. See also Fig. 232, in which we have the scalenohedral faces extended to complete the form. The pyramidal faces used are marked +, and the suppressed faces marked —. The result of extending the shaded faces in Fig. 229 is to produce a form bounded by twelve similar *Scalene* triangles; hence its name. See Fig. 140.

If we also extend the non-shaded pairs of planes

and suppress the others, we obtain a similar form as shown in Fig. 141. The first form is called **Positive,** and the second **Negative.**

The **Hexagonal Scalenohedron** is called Hexagonal to distinguish it from the Tetragonal Scalenohedron; but as the latter is so rare and is never found except in combination, it is customary to speak of the hexagonal form as the *Scalenohedron,* and when mentioning the tetragonal form, to designate it always as the *Tetragonal Scalenohedron.* See Figs. 196 and 197.

The **Hexagonal Scalenohedron** has six lateral edges above and six lateral edges below; and their terminal junctions mark the two ends of the vertical axis. The angles measured over the lateral edges are of two kinds—alternately acute and obtuse. The acute angles above are over the obtuse angles below; and the obtuse angles above are over the acute angles below. See Figs. 140, 141, 230–232, 244, 245, 252, 253, and 287–305.

The **Scalenohedron** has six equal lateral edges that zigzag about the crystal; while the *saw teeth* produced have equal sides, and are bisected by the lateral edges forming the obtuse angles. See Figs. 140, 141, 232, 244, 245, 252, and 253.

The selection of the Positive and Negative forms is an arbitrary matter, although much depends upon the other forms with which they are combined.

It is customary to consider a scalenohedron *positive* when it is so placed that the terminal edge next the observer is obtuse, and when the *saw tooth*, bisected by the terminal edge, has its point downwards. See Figs. 140 and 253.

When the terminal edge next to the observer is acute and the point of the *saw tooth* is turned upwards, the scalenohedron is *negative*. See Figs. 141 and 252.

It can be seen that the zigzag edges of the rhombohedron correspond to the zigzag edges of the scalenohedron; therefore, a rhombohedron can be inscribed in any scalenohedron which has a longer vertical axis than has the rhombohedron. The rhombohedron thus inscribed is known as the **Inscribed Rhombohedron** or the **Rhombohedron of the Middle Edges**. See Fig. 231.

The vertical axis of the scalenohedron is the prolonged vertical axis of the inscribed rhombohedron. Hence there may be an indefinite number of scalenohedrons for every inscribed rhombohedron; but in practice, it is found that the vertical semi-axis of the scalenohedron is always some simple multiple of the inscribed rhombohedron.

The Rhombohedral Group has three vertical planes of symmetry, which bisect the angles made by the lateral axes and coincide with the vertical axis. The group has also three horizontal axes of binary sym-

metry, which are coincident with the lateral axes. It has also one vertical axis of trigonal symmetry, which coincides with the vertical crystal axis; and a centre of symmetry.

B. The Pyramidal Group:

1. **Tertiary Hexagonal Prism:**
   a. **Positive or Right-handed.**
   b. **Negative or Left-handed.**
2. **Tertiary Hexagonal Pyramid:**
   a. **Positive or Right-handed.**
   b. **Negative or Left-handed.**

1. The **Tertiary Hexagonal Prism** or **Prism of the Third Order,** taken as a hemihedral form, can be considered to be produced by the suppression of each alternate plane of the dihexagonal prism and by the extension of the sides of the remaining alternate planes until they meet. See Figs. 213, 219, and 242. The form thus produced is identical in appearance with the Primary and Secondary Hexagonal Prisms, and it differs only in the positions of the lateral axes. A hexagonal prism will be considered a **Tertiary Hexagonal Prism,** only when its relation to the other forms and to the selected lateral axes shows that it cuts all three lateral axes unequally. This fact can readily be seen when a **Tertiary Hexagonal Prism** is united as a subordinate form with a dominant Primary or Secondary Prism, especially if there are a number of other subordinate forms.

By alternating the planes that we consider suppressed and those that we regard as extended, two prisms can be obtained which are called **Positive or Right-handed** and **Negative or Left-handed.**

In the above cases, when the positive or negative sign is employed, the sign for the right-handed or left-handed forms is omitted. So, when the *r* or *l* is used, the positive or negative sign is dropped. This is the custom in all cases where the positive or negative, or right-handed or left-handed, symbols are employed.

In giving the signs on the figures in this book, especially when they are first used, both the positive and the right-handed, or the negative and the left-handed signs are given in order to impress upon the student the idea that either sign can be used with the Naumann symbols.

2. The **Tertiary Hexagonal Pyramid** can be regarded as formed from the dihexagonal pyramid by the extension of an alternate plane above and its adjacent plane immediately below, (these planes stand base to base), and by the suppression of like alternate pairs of planes. See Fig. 234.

The two planes in each case would, if made parallel to the vertical axis, unite into one plane coincident with a prism plane.

Two sets of tertiary pyramids can thus be formed: **Positive** or **Right-handed** and **Negative** or **Left-handed.**

The relation of the Tertiary Pyramid to the Primary and the Secondary Pyramids is the same as previously stated for the three prisms.

It follows from what has been previously said that neither the Tertiary Prism nor the Tertiary Pyramid can occur except in combination with other hexagonal forms.

The Tertiary Hexagonal Prisms and Pyramids have an axis of hexagonal symmetry that is coincident with the vertical axis. They also possess a plane of symmetry that is coincident with the plane of the lateral axes; and a centre of symmetry.

C. Trapezohedral Group:

1. Hexagonal Trapezohedron:

a. Positive or Right-handed.

b. Negative or Left-handed.

The **Hexagonal Trapezohedral Group** does not occur among minerals, but is met with in artificial crystals and in crystal models.

The forms of this group can be considered to be produced by the suppression of the alternate upper and lower planes of the dihexagonal pyramid and by the extension of the other alternate planes until they meet. See Fig. 241. The form produced is a twelve-faced figure with unequal zigzag edges. By extending the planes previously suppressed and by obliterating the planes previously extended, another form is

produced, which is similar to the preceding form, just as a man's left hand is similar to his right hand. The first form is called the **Positive** or **Right-handed Hexagonal Trapezohedron** (see Fig. 210); and the second form is named the **Negative** or **Left-handed Hexagonal Trapezohedron.** See Fig. 211.

The Hexagonal Trapezohedrons have no plane of symmetry, but they have six horizontal axes of binary symmetry, (see p. 84), while the vertical crystal axis is an axis of hexagonal symmetry.

The Hexagonal Trapezohedron can be distinguished from other forms by the fact that its planes are in sixes; by the fact that all the angles formed by the edges which meet at the apices are equal; and by the further fact that the *saw-teeth* of its zigzag lateral edges have sides of unequal length, while in the Hexagonal Scalenohedron the zigzag edges have the sides of the *saw-teeth* equal. Further, because the alternate zigzag edges in the Hexagonal Trapezohedron are unequal, it happens that the edge angles below are not directly beneath the planes above, as they are in the Hexagonal Scalenohedron, but are thrown to one side or the other. Again, the faces of the Hexagonal Trapezohedron are *Trapeziums*, while those of the Hexagonal Scalenohedron are *Scalene Triangles.* See Figs. 140, 141, 210, 211, 252, and 253.

The right-handed Hexagonal Trapezohedrons can

be distinguished from the left-handed ones in the following manner: place the form so that one of the edges running to the apex will be directly in front of the observer and coincident with the plane of symmetry passing between his eyes. If the shorter side of the zigzag edge immediately in front inclines to the right-hand, the trapezohedron is right-handed; but if the shorter side is inclined towards the left-hand, the trapezohedron is left-handed. See Figs. 210 and 211.

D. Trigonal Group:

1. Ditrigonal Pyramid:

a. Positive.

b. Negative.

Of the **Trigonal Group** the only form to which attention is called here is the **Ditrigonal Pyramid,** since the other Trigonal forms are taken up elsewhere.

This form as a hemihedral form is considered to be produced by suppressing the alternate pairs of planes above and below of the dihexagonal pyramid, the pairs of planes standing base to base; and by extending the corresponding pairs of planes above and below, until the form is completed. See Fig. 326, in which the shaded pairs of planes denote the faces suppressed, while the non-shaded ones are the pairs of planes extended. Fig. 325 shows the resulting form. By varying the planes to be suppressed both **Positive** and **Negative** forms are produced.

These forms possess four planes of symmetry: one is horizontal and coincident with the plane of the lateral axes; the other three are vertical and bisect the angles between the lateral axes, as also do the three axes of binary symmetry. The vertical axis is an axis of trigonal symmetry.

No minerals have been found in the forms of this group.

III. TETARTOHEDRAL FORMS

A. Rhombohedral Group:
- **1. Secondary Rhombohedron:**
  - **a. Positive:**
    - *u.* **Right-handed.**
    - *w.* **Left-handed.**
  - **b. Negative:**
    - *x.* **Right-handed.**
    - *z.* **Left-handed.**
- **2. Tertiary Rhombohedron:**
  - **a. Positive:**
    - *u.* **Right-handed.**
    - *w.* **Left-handed.**
  - **b. Negative:**
    - *x.* **Right-handed.**
    - *z.* **Left-handed.**

1. The **Secondary Rhombohedron** or **Rhombohedron of the Second Order** can be regarded as obtained by the suppression of the alternate upper and lower faces of the secondary pyramid and the extension of the others. See Fig. 243. The **Secondary Rhombohedron**

differs in no way from the Primary Rhombohedron except in the position of the axes. Two of its lateral indices are equal, while the third is twice as great as the others. The **Secondary Rhombohedron** never occurs alone, but is always found in combination with other forms, the positions of whose axes will indicate the nature of the associated rhombohedrons.

By alternation of the planes to be extended and those to be suppressed two **Secondary Rhombohedrons** are obtained: **Positive** and **Negative**, either of which may be **Right-handed** or **Left-handed.**

2. The **Tertiary Rhombohedron** or **Rhombohedron of the Third Order** can be considered to be formed by the suppression of the alternate upper and lower planes of the hexagonal scalenohedron, and by the extension of the other alternate planes until they make a completed form. Each scalenohedron will produce two forms, and since there are two hexagonal scalenohedrons, we shall have four Tertiary Rhombohedrons. See Figs. 244 and 245.

The Tertiary Rhombohedron differs in no respect from the Primary or the Secondary Rhombohedron except in the position of its axes; but as it is always found in combination with other forms, the position of the axes of the latter will tell whether a given rhombohedral plane belongs to a **Primary, Secondary,** or **Tertiary Rhombohedron.** Of the lateral indices of the

Tertiary Rhombohedron, one is unity, one twice, and one three times as great.

On account of the difference in the position of their axes the Secondary and the Tertiary Rhombohedrons have a lower order of symmetry than has the Primary Rhombohedron. The first two have no planes of symmetry, but do have a centre of symmetry and an axis of trigonal symmetry that is coincident with the vertical axis of the crystal.

B. Trapezohedral Group:
- **1. Secondary Trigonal Prism:**
  - **a. Positive or Right-handed.**
  - **b. Negative or Left-handed.**
- **2. Ditrigonal Prism:**
  - **a. Positive or Right-handed.**
  - **b. Negative or Left-handed.**
- **3. Secondary Trigonal Pyramid:**
  - **a. Positive:**
    - *u.* **Right-handed.**
    - *w.* **Left-handed.**
  - **b. Negative:**
    - *x.* **Right-handed.**
    - *z.* **Left-handed.**
- **4. Trigonal Trapezohedron:**
  - **a. Positive:**
    - *u.* **Right-handed.**
    - *w.* **Left-handed.**
  - **b. Negative:**
    - *x.* **Right-handed.**
    - *z.* **Left-handed.**

1. The **Secondary Trigonal Prism** or **Trigonal Prism of the Second Order** can be considered to have been produced by the suppression of each alternate plane of the secondary hexagonal prism and the extension of the other three faces until they meet. Figure 220, by its shading, shows the planes that are supposed to be suppressed on this form, while the non-shaded planes are those supposed to be extended. Figure 221 is a representation of the form produced.

By imagining the preceding shaded planes of the secondary hexagonal prism extended and the non-shaded ones suppressed, another Secondary Trigonal Prism will be produced. One prism can then be called the **Positive** or **Right-handed** and the other the **Negative** or **Left-handed.**

2. The **Ditrigonal Prism** can be looked upon as produced by the extension of alternate pairs of planes of the dihexagonal prism and by the suppression of the other alternate pairs of planes. As before, by interchanging the planes to be extended, two forms are produced: The **Positive** or **Right-handed** and the **Negative** or **Left-handed.** See Figs. 219, 230, and 246–248.

3. The **Secondary Trigonal Pyramid** is regarded as formed from the secondary hexagonal pyramid by extending the three alternate planes above and also the three alternate planes below, whose bases are coincident with the bases of the extended planes above. The

other alternate planes are suppressed. See Fig. 249, in which the shaded planes are the ones that are here considered suppressed.

By extending the planes previously considered suppressed and by obliterating the others, another companion form is produced, giving us **Positive** or **Right-handed** and **Negative** or **Left-handed Trigonal Pyramids**. See Figs. 250 and 251.

4. The Trigonal Trapezohedron can be looked upon as being formed by the extension, in the scalenohedron, of every other plane above and of the planes immediately below (i. e., the alternate upper and lower planes whose bases join), and by the suppression of the other six planes. See Figs. 252 and 253.

By alternating the planes extended and those suppressed, two forms can be produced for the positive and two for the negative scalenohedron, or four in all. These are designated as **Positive Right-** or **Left-handed,** and **Negative Right-** or **Left-handed.** See Figs. 54 and 55.

The **Trigonal Trapezohedrons** are always found in combination with other forms, and never occur isolated in nature. See $\frac{6P\frac{6}{5}}{4}$, Figs. 308–312. The group possesses three axes of binary symmetry coincident with the lateral axes, and an axis of trigonal symmetry coincident with the vertical axis, but it has neither plane nor centre of symmetry.

C. Trigonal Group :

- **1. Primary Trigonal Prism :**
  - **a. Positive.**
  - **b. Negative.**
- **2. Tertiary Trigonal Prism :**
  - **a. Positive :**
    - *u.* **Right-handed.**
    - *w.* **Left-handed.**
  - **b. Negative :**
    - *x.* **Right-handed.**
    - *z.* **Left-handed.**
- **3. Primary Trigonal Pyramid :**
  - **a. Positive.**
  - **b. Negative.**
- **4. Tertiary Trigonal Pyramid :**
  - **a. Positive :**
    - *u.* **Right-handed.**
    - *w.* **Left-handed.**
  - **b. Negative :**
    - *x.* **Right-handed.**
    - *z.* **Left-handed.**

1. The **Primary Trigonal Prism** can be considered to be produced by proceeding with the primary hexagonal prism as was done with the secondary hexagonal prism to form the secondary trigonal prism. See page 99. Two forms result—**Positive** and **Negative.**

2. The **Tertiary Trigonal Prism** can be considered to be formed by extending every fourth plane of the dihexagonal prism until they meet, and by suppressing the other three-fourths. By varying the planes extended, four forms can be produced : **Positive Right-**

and **Left-handed**, and **Negative Right-** and **Left-handed.**

3. The **Primary Trigonal Pyramid** as a tetartohedral form is considered to be produced from the primary hexagonal pyramid in the same way in which the secondary trigonal pyramid was made. See page 99. Two forms result, **Positive** and **Negative.**

4. The **Tertiary Trigonal Pyramid** as a tetartohedral form can be regarded as produced by extending every fourth upper and lower plane (arranged base to base) of the dihexagonal pyramid and suppressing the other three-fourths. By varying the planes to be extended, four forms result: **Positive Right-** and **Left-handed**, and **Negative Right-** and **Left-handed.**

These trigonal forms have one horizontal plane of symmetry coincident with the plane of the lateral axes, and an axis of trigonal symmetry coincident with the vertical axis, but are destitute of any centre of symmetry.

HEMIMORPHIC FORMS.

1. The **Iodyrite Type** is shown in Figs. 214–216.

Fig. 214 is terminated at one end by a hexagonal pyramid ($10\bar{1}1$), and has upon the other end a hexagonal prism ($10\bar{1}0$), and a basal pinacoid ($000\bar{1}$). Figures 215 and 216 have one end terminated by a basal pinacoid (0001) and a pyramid ($40\bar{4}1$), and the other end terminated by pyramids (see Fig. 215, $40\overline{45}$

and $9{\cdot}9{\cdot}\overline{18}{\cdot}20$),* or by a pyramid (see Fig. 216, 4045). A prism ($11\bar{2}0$) lies between the terminal pyramids.

The **Iodyrite Type** has six vertical planes of symmetry, and a vertical axis of hexagonal symmetry coincident with the vertical axis.

2. The **Nephelite Type** may be distinguished by the fact that the terminations at opposite ends of the vertical axis are composed of different hexagonal pyramids, or by the fact that the crystal is formed by half of a hexagonal pyramid resting on its basal pinacoid. Figure 217 illustrates well one of the first set of forms. This type has an axis of hexagonal symmetry.

3. The **Tourmaline Type** is most commonly represented by prisms, terminated at each end by diverse rhombohedrons. These forms have three vertical planes of symmetry that bisect the lateral axial angles, and an axis of trigonal symmetry that is coincident with the vertical crystal axis. See Fig. 324.

4. The **Sodium-Periodate Type** is formed by taking the upper or lower part of a trigonal pyramid and terminating it by a basal pinacoid, as shown by Fig.

* When, as occasionally happens, the Miller-Bravais indices are so large that a single index contains two figures, it is customary to avoid mistakes in the indices by separating each index by a point at the upper part of the line. See above and $11{\cdot}2{\cdot}\overline{13}{\cdot}3$ and $14{\cdot}14{\cdot}\overline{28}{\cdot}3$. Others use the points below, *e. g.*, 10.5.6, $9.8.\overline{17}.1$, and $7.4.\overline{11}.6$. Others employ commas, *e. g.*, 6,4,10,4; 16,0,16,1; and $9,9,\overline{18},20$. Still others omit all points of separation.

327. These forms have one vertical axis of trigonal symmetry coincident with the vertical crystallographic axis.

COMPOUND FORMS.

The compound forms of the Hexagonal system are numerous and varied. Of these the combinations of the hemihedral and tetartohedral forms are more common and important than are the compound holohedral forms.

The student should take especial care in deciding which is the principal form and in determining the positions of its axes, since upon them depends the ease or difficulty in naming the subordinate forms.

References to the figures of hexagonal crystals given in this book will show that the majority of them are compound, and that some are more or less complicated. See Figs. 36–40, 45–50, 54, 55, 138–141, 202–234, and 241–327.

RULES FOR NAMING HEXAGONAL PLANES.

I. A plane parallel to all the lateral axes is a **Basal Pinacoid** or a **Basal Plane.**

II. A plane which is parallel to the vertical axis and one of the lateral axes, but which cuts the other two lateral axes equally, is a plane belonging to a **Primary Prism**:

a. If the number of similar planes is *six*, each plane belongs to a **Primary Hexagonal Prism** or **Hexagonal Prism of the First Order.**

b. If the number of similar planes is *three*, each plane belongs to a **Primary Trigonal Prism** or **Trigonal Prism of the First Order.**

III. If a plane is parallel to the vertical axis and cuts one lateral axis at some distance, and the other two lateral axes at twice that distance, the plane belongs to a **Secondary Prism**:

a. If the number of similar planes is *six*, each plane belongs to a **Secondary Hexagonal Prism** or **Hexagonal Prism of the Second Order.**

b. If the number of similar planes is *three*, each plane belongs to a **Secondary Trigonal Prism** or **Trigonal Prism of the Second Order.**

IV. If the plane is parallel to the vertical axis and intersects all three lateral axes at unequal distances, the plane belongs to a **Dihexagonal Prism** or to one of its partial forms:

a. If the number of similar planes is *twelve*, then each plane belongs to a **Dihexagonal Prism.**

b. If the number of similar planes is *six*, each plane belongs to a **Tertiary Hexagonal Prism** or **Hexagonal Prism of the Third Order,** provided its lateral angles are equal; but if the lateral angles are alternately unequal,* then each plane belongs to a **Ditrigonal Prism.**

* In this case three of the alternate angles are equal to one another, while the three other alternate angles are unequal to the first three, but they are all equal to one another.

c. If the number of similar planes is *three*, then each plane belongs to a **Tertiary Trigonal Prism** or **Trigonal Prism of the Third Order.**

V. If a plane intersects the vertical axis, is parallel to one lateral axis, and cuts the other two lateral axes at equal distances, it belongs to a **Primary Pyramid** or to some one of its partial forms:

a. If the number of similar planes at each end is *six*, then each plane belongs to a **Primary Hexagonal Pyramid** or **Hexagonal Pyramid of the First Order**.

b. When the number of similar planes at each end is *three*, and the figure is placed with the vertical axis perpendicular, if the faces are rhombohedral and the lateral edges inclined to the horizon, then each plane belongs to a **Rhombohedron,** but if the faces are triangular and the lateral edges horizontal, then each plane belongs to a **Primary Trigonal Pyramid** or **Trigonal Pyramid of the First Order**.

VI. If a plane cuts the vertical axis and intersects one lateral axis at a unit of distance, cutting the other two at twice that distance, it is a plane belonging to a **Secondary Pyramid** or to some of its partial forms:

a. If the number of similar planes at each end is *six*, then each plane belongs to a **Secondary Hexagonal Pyramid** or **Hexagonal Pyramid of the Second Order.**

b. When the number of similar planes at each end is *three*, and the figure is placed with the vertical axis

perpendicular, if the faces are rhombohedral and the lateral edges inclined to the horizon, then each plane belongs to a **Secondary Rhombohedron,** but if the faces are triangular and the lateral edges horizontal, then each plane belongs to a **Secondary Trigonal Pyramid** or **Trigonal Pyramid of the Second Order.**

VII. If a plane cuts the vertical axis and intersects all the lateral axes at unequal distances, the plane belongs to a **Dihexagonal Pyramid** or to some one of its partial forms:

a. If the number of similar planes at each end of the crystal is *twelve,* then each plane belongs to a **Dihexagonal Pyramid.**

b. If the number of similar planes at each end of the crystal is *six,* then each plane belongs to one of the four following *hemihedral* or *half forms:* (1) If the alternate terminal angles are unequal (three and three) and the lateral edges are zigzag and equal, then each plane belongs to a **Scalenohedron**; (2) if the terminal angles are all equal and the edges horizontal, then each plane belongs to the **Tertiary Hexagonal Pyramid**; (3) if the terminal angles are equal and the lateral edges zigzag and unequal, each plane belongs to a **Hexagonal Trapezohedron**; (4) if the alternate terminal angles are unequal (three and three) and the lateral edges horizontal, each plane belongs to the **Ditrigonal Pyramid.**

c. If the number of similar planes at each end of the crystal is *three*, then each plane may belong to one of the three following *tetartohedral* or *quarter forms:* (1) If the faces are rhombohedral and the edges oblique to the horizontal plane, each face belongs to a **Tertiary Rhombohedron** or **Rhombohedron of the Third Order**; (2) if the faces are trapeziums with unequal lateral zigzag edges, each face belongs to a **Trigonal Trapezohedron**; (3) if the terminal angles are all equal, and if the faces, triangles, and the lateral edges are horizontal, then each face belongs to the **Tertiary Trigonal Pyramid** or **Trigonal Pyramid of the Third Order.***

VIII. If the opposite ends of the crystal are unlike, the forms are **Hemimorphic**

a. If the form is composed of a hemi-dihexagonal pyramid and a basal plane, or of hemi-dihexagonal and primary or secondary pyramids and prisms with a basal plane, then the form belongs to the **Iodyrite Type.**

* The statements that the lateral edges are oblique or horizontal, and that the planes are triangles, etc., refer to a complete single form. In the case of compound forms the various planes so modify one another that the positions of the lateral edges and the shapes of the planes are much varied. In such cases the student will need to refer to the text for the relative positions of the planes in each case, or to reconstruct the complete form for each set of similar planes when handling complicated compound forms, until he has had sufficiently extended practice in this work to enable him to recognize readily the forms from the positions of their planes.

b. If the form is composed of hexagonal pyramids and prisms with or without one or two basal planes, then the form belongs to the **Nephelite Type**.

c. If the form consists of a hemi-hexagonal or ditrigonal pyramid terminated by a basal plane, or of hexagonal prisms terminated by hemi-hexagonal pyramids and by basal planes, or of hexagonal, ditrigonal, and trigonal prisms terminated by hemi-rhombohedrons, and with or without hemi-hexagonal pyramids, the form belongs to the **Tourmaline Type**.

d. If the form consists of a hemi-trigonal pyramid or pyramids with or without trigonal prisms, and terminated on the base by a pinacoid, the form belongs to the **Sodium-Periodate Type**.*

READING DRAWINGS OF HEXAGONAL CRYSTALS.

The four axes of the Hexagonal system render the crystallographic shorthand in that system more complicated than in the preceding systems.

The lettering of the semi-axes is shown in Fig. 6 and noted on page 75. In the preceding systems the front semi-axis and the right semi-axis are considered as *positive*, while those semi-axes extending to the rear

* To distinguish between these hemimorphic types is not easy, and the rules above given are far from accurate, especially in the case of the first three types. Frequent reference will have to be made to the text; to the centres, axes and planes of symmetry; to the positions of the crystallographic axes, and to the figures given in the plates.

and to the left are considered *negative.* Further, the parameter or index of the semi-axis extending forwards or backwards is read first, and that belonging to the semi-axis extending to the right or left, as the case may be, is read secondly. In the Hexagonal system the method of reading the lateral semi-axes is changed. Commencing with the semi-axis in front and considering that as *positive*, we call the next semi-axis to the right *negative.* Continuing to read the parameters or indices of the lateral semi-axes from the right around to the rear and to the left of the vertical axis, we designate the third lateral semi-axis as *positive*, the fourth *negative*, the fifth *positive*, and the sixth *negative;* or the signs of the axes alternate as we read around the vertical axis either from right to left or left to right.

In reading the parameters or indices, it is the approved modern method to read first the parameter belonging to the lateral semi-axis in the front or in the rear; secondly, that of the third lateral semi-axis to the right or the left, and thirdly, that of the second lateral semi-axis. As in the other systems, the vertical semi-axis is given last, and is called *positive* when above the lateral axes and *negative* when below them.

It should be observed, then, that at least one of the lateral parameters or indices of any plane or form in the Hexagonal system is always negative (see page 75), while some of the others may be. In the Miller-

Bravais notation the majority of crystallographers use i for the second lateral semi-axis, i. e., for the axis that lies to the right of the lateral semi-axis in the front. It should further be observed that in this notation the amount of the lateral negative integer or integers is exactly equal to the amount of the lateral positive integer or integers.

As before, the hemihedral forms are distinguished, in the Weiss notation, by writing $\frac{1}{2}$ before the symbols of the form or plane, or, in the Naumann notation, by writing 2 as the denominator of a fraction, whose numerator is the symbol of the corresponding holohedral form.

In the same way the tetartohedral planes and forms are designated by writing $\frac{1}{4}$ before the Weiss symbol, or, in the Naumann notation, by using 4 as the denominator and the symbol of the holohedral form as the numerator in each case.

In the Miller-Bravais notation the hemihedral planes and forms are indicated by some Greek letter written before the indices, while those which are tetartohedral are designated by any two Greek letters placed before the symbols. Further, when the hemihedral, or selected tetartohedral forms can be easily known as such by the context or by the figure, the Greek letters are often omitted before the symbols.

Most of these symbols are quite easily understood

when they are compared with those of preceding systems as shown in the various tables.

The symbols or crystallographic shorthand employed in the cases of the rhombohedrons and scalenohedrons in the Naumann system require special mention. According to the method of derivation of the fundamental primary rhombohedron (see page 85), its symbol in the usual form would be $\frac{P}{2}$, but in the Naumann system this is usually abbreviated as R. In the cases of the subordinate primary rhombohedrons the usual symbol would be $\frac{mP}{2}$, but this is abbreviated as mR, in which the m may be $\frac{1}{4}$, $\frac{3}{10}$, $\frac{2}{5}$, $\frac{1}{2}$, 1, $\frac{7}{4}$, $\frac{5}{2}$, 3, 4, $\frac{9}{2}$, 6, 7, and so on.

The more obvious symbols for the scalenohedrons are $\frac{Pn}{2}$ for the principal forms, and $\frac{mPn}{2}$ for the subordinate forms, but these are commonly written as Rn and mRn in the Naumann system. Dana further abbreviates these as m^n.

Since the rhombohedrons and scalenohedrons are much more common than are the holohedral forms, it is a matter of convenience to dispense with the fractional symbols in the former.

In the hemimorphic forms, since the opposite ends of the crystals are unlike, the letter *o* is employed to

designate the forms that are *over* or upon the upper portion of the crystals, and the letter *u* is used to indicate those on the *under* or lower part of the crystal. The employment of the initial *o* for *over* and *u* for *under* conduces not only to convenience in the use of other texts but also to uniformity, since the German crystallographers employ the same letters: *o* for *ober* and *u* for *unter*.

In the same way, crystallographers use *r* for *right* (*rechts*) or *right-handed* and *l* for *left* (*links*) or *left-handed* in connection with the symbols of right-handed or left-handed forms.

TABLE V

HEXAGONAL FORMS AND NOTATIONS

Forms.	Weiss.	Naumann.	Dana.	Miller-Bravais.
Basal Pinacoids.	$\infty a : \infty a : \infty \bar{a} : c$	$0P$	O or c	0001
Primary Hexagonal Prisms.	$a : \infty a : -a : \infty c$	∞P	I or m	$10\bar{1}0$
Secondary Hexagonal Prisms.	$2a : 2a : -a : \infty c$	$\infty P2$	$i\text{-}2$ or a	$11\bar{2}0$
Tertiary Hexagonal Prisms.	$\frac{1}{2}[na : pa : -a : \infty c]$ $-\frac{1}{2}[na : pa : -a : \infty c]$	$\left[\frac{\infty Pn}{2}\right]r$ $-\left[\frac{\infty Pn}{2}\right]l$	$\left[\frac{i\text{-}n}{2}\right]r$ $-\left[\frac{i\text{-}n}{2}\right]l$	$\pi\{hk\bar{i}0\}$ $\pi\{i\bar{k}\bar{h}0\}$
Dihexagonal Prisms.	$\frac{3}{2}a : 3a : -a : \infty c$ $na : pa : -a : \infty c$	$\infty P\frac{3}{2}$ ∞Pn	$i\ \frac{3}{2}$ $i\ n$	$21\bar{3}0$ $hk\bar{i}0$
Primary Hexagonal Pyramids.	$a : \infty a : -a : c$ $a : \infty a : -a : mc$	P mP	1 m	$10\bar{1}1$ $h0\bar{h}l$
Secondary Hexagonal Pyramids.	$2a : 2a : -a : c$ $2a : 2a : -a : mc$	$P2$ $mP2$	$1\text{-}2$ $m\text{-}2$	$11\bar{2}2$ $h \cdot h \cdot \overline{2h} \cdot l$

TABLE V—*Continued*

Form.	Weiss.	Naumann.	Dana.	Miller-Bravais.
Tertiary Hexagonal Pyramids.	$\frac{1}{2}[na : pa : -a : mc]r$	$\left[\frac{mPn}{2}\right]r$	$\left[\frac{m\text{-}\bar{n}}{2}\right]r$	$\pi\{hk\bar{i}l\}$
	$-\frac{1}{2}[na : pa : -a : mc]l$	$-\left[\frac{mPn}{2}\right]l$	$-\left[\frac{m\text{-}\bar{n}}{2}\right]l$	$\pi\{i\bar{k}\bar{h}l\}$
Dihexagonal Pyramids.	$\frac{3}{2}\ a : 3a : -a : 3c$	$3P\frac{3}{2}$	$3\text{-}\frac{3}{2}$	$21\bar{3}1$
	$na : pa : -a : mc$	mPn	$m\text{-}n$	$hk\bar{i}l$
Primary Trigonal Prisms.	$\frac{1}{4}(a : \infty a : -a : \infty c)$	$\frac{\infty P}{4}$	$\frac{i}{4}$	$\kappa\tau\{10\bar{1}0\}$
	$-\frac{1}{4}(a : \infty a : -a : \infty c)$	$-\frac{\infty P}{4}$	$-\frac{i}{4}$	$\kappa\tau\{01\bar{1}0\}$
Secondary Trigonal Prisms.	$\frac{1}{4}(2a : 2a : -a : \infty c)$	$\frac{\infty P2}{4}r$	$\frac{i\text{-}2}{4}r$	$\kappa\tau\{h \cdot h \cdot 2\bar{h} \cdot 0\}$
	$-\frac{1}{4}(2a : 2a : -a : \infty c)$	$-\frac{\infty P2}{4}l$	$-\frac{i\text{-}2}{4}l$	$\kappa\tau\{2h \cdot \bar{h} \cdot \bar{h}\ 0\}$
Tertiary Trigonal Prisms.	$\frac{1}{4}(na : pa : -a : \infty c)r$	$\frac{\infty Pn}{4}r$	$\frac{i\text{-}n}{4}r$	$\kappa\tau\{hk\bar{i}0\}$
	$\frac{1}{4}(na : pa : -a : \infty c)l$	$\frac{\infty Pn}{4}l$	$\frac{i\text{-}n}{4}l$	$\kappa\tau\{kh\bar{i}0\}$
	$-\frac{1}{4}(na : pa : -a : \infty c)r$	$-\frac{\infty Pn}{4}r$	$-\frac{i\text{-}n}{4}r$	$\kappa\tau\{i\bar{k}\bar{h}0\}$
	$-\frac{1}{4}(na : pa : -a : \infty c)l$	$-\frac{\infty Pn}{4}l$	$-\frac{i\text{-}n}{4}l$	$\kappa\tau\{i\bar{h}\bar{k}0\}$

TABLE V—*Continued*

Forms.	Weiss.	Naumann.	Dana.	Miller-Bravais.
Ditrigonal Prisms.	$\frac{1}{4}(na : pa : -a : \infty c)r$	$\frac{\infty Pn}{4}r$	$\frac{i\text{-}n}{4}r$	$\kappa\tau\{hk\bar{i}0\}$
	$-\frac{1}{4}(na : pa : -a : \infty c)l$	$-\frac{\infty Pn}{4}l$	$-\frac{i\text{-}n}{4}l$	$\kappa\tau\{i\bar{k}\bar{h}0\}$
Primary Trigonal Pyramids.	$\frac{1}{4}(a : \infty a : -a : c)$	$\frac{mP}{4}$	$\frac{i}{4}$	$\kappa\tau\{h0\bar{h}l\}$
	$-\frac{1}{4}(a : \infty a : -a : c)$	$-\frac{mP}{4}$	$-\frac{i}{4}$	$\kappa\tau\{0h\bar{h}l\}$
Secondary Trigonal Pyramids.	$\frac{1}{4}(2a : 2a : -a : mc)r$	$\frac{mP2}{4}r$	$\frac{m\text{-}2}{4}r$	$\kappa\tau\{h \cdot h \cdot \overline{2h} \cdot l\}$
	$-\frac{1}{4}(2a : 2a : -a : mc)l$	$-\frac{mP2}{4}l$	$-\frac{m\text{-}2}{4}l$	$\kappa\tau\{2h \cdot \bar{h} \cdot \bar{h} \cdot l\}$
Tertiary Trigonal Pyramids.	$\frac{1}{4}(na : pa : -a : mc)r$	$\frac{mPn}{4}r$	$\frac{m\text{-}n}{4}r$	$\kappa\tau\{hk\bar{i}l\}$
	$\frac{1}{4}(na : pa : -a : mc)l$	$\frac{mPn}{4}l$	$\frac{m\text{-}n}{4}l$	$\kappa\tau\{kh\bar{i}l\}$
	$-\frac{1}{4}(na : pa : -a : mc)r$	$-\frac{mPn}{4}r$	$-\frac{m\text{-}n}{4}r$	$\kappa\tau\{i\bar{k}\bar{h}l\}$
	$-\frac{1}{4}(na : pa : -a : mc)l$	$-\frac{mPn}{4}l$	$-\frac{m\text{-}n}{4}l$	$\kappa\tau\{i\bar{h}\bar{k}l\}$

TABLE V—*Continued*

Forms.	Weiss.	Naumann.	Dana.	Miller-Bravais.
Ditrigonal Pyramids.	$\frac{1}{2}(na:\ pa:-a:mc)$	$\frac{mPn}{2}$	$\frac{m\text{-}n}{2}$	$\kappa\{hkil\}$
	$-\frac{1}{2}(na:\ pa:-a:mc)$	$-\frac{mPn}{2}$	$-\frac{m\text{-}n}{2}$	$\kappa\{ik\bar{h}l\}$
Primary Rhombohedrons.	$\frac{1}{2}(\ a:\infty a:-a:c)$	$\frac{P}{2}$ or R	1	$\kappa\{10\bar{1}1\}$
	$-\frac{1}{2}(\ a:\infty a:-a:c)$	$-\frac{P}{2}$ or $-R$	-1	$\kappa\{0\bar{1}11\}$
	$\frac{1}{2}(\ a:\infty a:-a:mc)$	$\frac{mP}{2}$ or mR	mr or $\frac{m}{2}$	$\kappa\{h0\bar{h}l\}$
	$-\frac{1}{2}(\ a:\infty a:-a:mc)$	$-\frac{mP}{2}$ or $-mR$	$-mr$ or $\frac{m}{2}$	$\kappa\{0\bar{h}hl\}$
Secondary Rhombohedrons.	$\frac{1}{4}(2a:\ 2a:-a:mc)\frac{r}{l}$	$\frac{mP2}{4}\ \frac{r}{l}$	$\frac{m\text{-}2}{4}\ \frac{r}{l}$	$\pi\kappa\{h{\cdot}h{\cdot}\overline{2h}{\cdot}l\}$
	$-\frac{1}{4}(2a:\ 2a:-a:mc)\frac{l}{r}$	$\frac{mP2}{4}\ \frac{l}{r}$	$-\frac{m\text{-}2}{4}\ \frac{l}{r}$	$\pi\kappa\{2h{\cdot}\bar{h}{\cdot}\bar{h}{\cdot}l\}$
Tertiary Rhombohedrons.	$\frac{1}{4}(na:\ pa:-a:mc)r$	$\frac{mPn}{4}r$	$\frac{m\text{-}n}{4}r$	$\pi\kappa\{hkil\}$
	$\frac{1}{4}(na:\ pa:-a:mc)l$	$\frac{mPn}{4}l$	$\frac{m\text{-}n}{4}l$	$\pi\kappa\{ik\bar{h}l\}$
	$-\frac{1}{4}(na:\ pa:-a:mc)r$	$-\frac{mPn}{4}r$	$-\frac{m\text{-}n}{4}r$	$\pi\kappa\{\bar{k}i\bar{h}l\}$
	$-\frac{1}{4}(na:\ pa:-a:mc)l$	$-\frac{mPn}{4}l$	$-\frac{m\text{-}n}{4}l$	$\pi\kappa\{khil\}$

TABLE V—*Continued*

Forms.	Weiss.	Naumann.	Dana.	Miller-Bravais.
Hexagonal Scalenohedrons.	$\frac{1}{2}(na:pa:-a:mc)$	$\frac{mPn}{2}$ or mRn	$\frac{m\text{-}n}{2}$ or mn	$\kappa\{hk\bar{i}l\}$
	$-\frac{1}{2}(na:pa:-a:mc)$	$-\frac{mPn}{2}$ or $-mRn$	$-\frac{m\text{-}n}{2}$ or $-mn$	$\kappa\{i\bar{k}\bar{h}l\}$
Hexagonal Trapezohedrons.	$\frac{1}{2}(na:pa:-a:mc)r$	$\frac{mPn}{2}r$	$\frac{mn}{2}r$	$\tau\{hk\bar{i}l\}$
	$-\frac{1}{2}(na:pa:-a:mc)l$	$-\frac{mPn}{2}l$	$-\frac{mn}{2}l$	$\tau\{khil\}$
Trigonal Trapezohedrons.	$\frac{1}{4}(na:pa:-a:mc)r$	$\frac{mPn}{4}r$	$\frac{m\text{-}n}{4}r$	$\kappa\tau\{hk\bar{i}l\}$
	$\frac{1}{4}(na:pa:-a:mc)l$	$\frac{mPn}{4}l$	$\frac{m\text{-}n}{4}l$	$\kappa\tau\{\bar{i}\bar{k}\bar{h}l\}$
	$-\frac{1}{4}(na:pa:-a:mc)r$	$-\frac{mPn}{4}r$	$-\frac{m\text{-}n}{4}r$	$\kappa\tau\{\bar{k}i\bar{h}l\}$
	$-\frac{1}{4}(na:pa:-a:mc)l$	$-\frac{mPn}{4}l$	$-\frac{m\text{-}n}{4}l$	$\kappa\tau\{kh\bar{i}l\}$
Iodyrite Type.	$\frac{1}{2}(na:pa:-a:mc)o$	$\frac{mPn}{2}o$	$\frac{m\text{-}n}{2}o$	$\kappa\{hk\bar{i}l\}$
	$-\frac{1}{2}(na:pa:-a:mc)u$ etc.	$-\frac{mPn}{2}u$ etc.	$-\frac{m\text{-}n}{2}u$ etc.	$\kappa\{hk\bar{i}\bar{l}\}$ etc.

TABLE V—*Continued*

Form.	Weiss.	Naumann.	Dana.	Miller-Bravais.
Nephelite Type.	$\frac{1}{4}[\,na : pa : -a : mc]o$	$\left[\frac{mPn}{2}\right]o$	$\left[\frac{m\text{-}n}{2}\right]o$	$\pi\{hk\bar{i}l\}$
	$-\frac{1}{4}[\,na : pa : -a : mc]o$	$-\left[\frac{mPn}{2}\right]o$	$-\left[\frac{m\text{-}n}{2}\right]o$	$\pi\{i\bar{k}\bar{h}l\}$
	$\frac{1}{4}[\,na : pa : -a : mc]u$	$\left[\frac{mPn}{2}\right]u$	$\left[\frac{m\text{-}n}{2}\right]u$	$\pi\{hk\bar{i}\bar{l}\}$
	$-\frac{1}{4}[\,na : pa : -a : mc]u$	$-\left[\frac{mPn}{2}\right]u$	$-\left[\frac{m\text{-}n}{2}\right]u$	$\pi\{i\bar{k}\bar{h}\bar{l}\}$
	etc.	etc.	etc.	etc.
Tourmaline Type.	$(\infty a : \infty a : \infty a : c)o$	$o.0P$ or $o.0R$	$o\ o$	$\kappa\{0001\}$
	$(\infty a : \infty a : \infty a : c)u$	$u.0P$ or $u.0R$	$o\ u$	$\kappa\{000\bar{1}\}$
	$\frac{1}{4}(\ a : \infty a : -a : mc)o$	$o+\frac{mP}{2}$ or $o+mR$	$\frac{m}{2}o$	$\kappa\{h0\bar{h}l\}$
	$-\frac{1}{4}(\ a : \infty a : -a : mc)o$	$o-\frac{mP}{2}$ or $o-mR$	$-\frac{m}{2}o$	$\kappa\{0h\bar{h}l\}$
	$\frac{1}{4}(\ a : \infty a : -a : mc)u$	$u+\frac{mP}{2}$ or $u+mR$	$\frac{m}{2}u$	$\kappa\{h0\bar{h}\bar{l}\}$
	$-\frac{1}{4}(\ a : \infty a : -a : mc)u$	$u-\frac{mP}{2}$ or $u-mR$	$\frac{m}{2}u$	$\kappa\{0h\bar{h}\bar{l}\}$

TABLE V—*Concluded*

Forms.	Weiss.	Naumann.	Dana.	Miller-Bravais.
Tourmaline Type.	$\frac{1}{2}(na : pa : -a : mc)o$	$o+\frac{mPn}{2}$ or $o+mRn$	$\frac{m\cdot n}{2}o$	$\kappa\{hk\bar{i}l\}$
	$-\frac{1}{2}(na : pa : -a : mc)o$	$o-\frac{mPn}{2}$ or $o-mRn$	$-\frac{m\cdot n}{2}o$	$\kappa\{i\bar{h}\bar{k}l\}$
	$\frac{1}{2}(na : pa : -a : mc)u$	$u+\frac{mPn}{2}$ or $u+mRn$	$\frac{m\cdot n}{2}u$	$\kappa\{hk\bar{i}\bar{l}\}$
	$-\frac{1}{2}(na : pa : -a : mc)u$	$u-\frac{mPn}{2}$ or $u-mRn$	$-\frac{m\text{-}n}{2}u$	$\kappa\{i\bar{h}\bar{k}\bar{l}\}$
	$(2a : 2a : -a : mc)o$	$o+mP2$	$o.m\text{-}2$	$\kappa\{h\,h\,\overline{2h}\cdot l\}$
	$(2a : 2a : -a : mc)u$	$u-mP2$	$u.m\text{-}2$	$\kappa\{h\cdot h\,\overline{2h}\cdot\bar{l}\}$
	$(na : pa : -a : \infty c)o$	$o+\infty Pn$	$o.i\text{-}n$	$\kappa\{hk\bar{i}0\}$
	$(na : pa : -a : \infty c)u$	$u-\infty Pn$	$u.i\text{-}n$	$\kappa\{i\bar{k}\bar{h}0\}$
	etc.	etc.	etc.	etc.
Sodium-Periodate Type.	$o\frac{(na : pa : -a : mc)r}{4}$	$o\frac{mPn}{4}r$	$o\frac{m\text{-}n}{4}r$	$\kappa\tau\{hk\bar{i}l\}$
	$o\frac{(na : pa : -a : mc)l}{4}$	$o\frac{mPn}{4}l$	$o\frac{m\cdot n}{4}l$	$\kappa\tau\{i\bar{k}\bar{h}l\}$
	$u\frac{(na : pa : -a : mc)r}{4}$	$u\frac{mPn}{4}r$	$u\frac{m\text{-}n}{4}r$	$\kappa\tau\{hk\bar{i}\bar{l}\}$
	$u\frac{(na : pa : -a : mc)l}{4}$	$u\frac{mPn}{4}l$	$u\frac{m\text{-}n}{4}l$	$\kappa\tau\{i\bar{k}\bar{h}\bar{l}\}$
	$o-\frac{(na : pa : -a : mc)r}{4}$	$o-\frac{mPn}{4}r$	$o-\frac{m\text{-}n}{4}r$	$\kappa\tau\{h\bar{i}kl\}$
	$o-\frac{(na : pa : -a : mc)l}{4}$	$o-\frac{mPn}{4}l$	$o-\frac{m\text{-}n}{4}l$	$\kappa\tau\{k\bar{i}hl\}$
	$u-\frac{(na : pa : -a : mc)r}{4}$	$u-\frac{mPn}{4}r$	$u-\frac{m\text{-}n}{4}r$	$\kappa\tau\{h\bar{i}k\bar{l}\}$
	$u-\frac{(na : pa : -a : mc)l}{4}$	$u-\frac{mPn}{4}l$	$u-\frac{m\text{-}n}{4}l$	$\kappa\tau\{k\bar{i}h\bar{l}\}$
	etc.	etc.	etc.	etc.

DIRECTIONS FOR STUDYING HEXAGONAL CRYSTALS

1. Prove that the crystal or model is hexagonal.

2. Locate the axes so as to make the forms as few and simple as possible, and place the crystal with the vertical axis erect.

3. Determine whether the vertical axis is coincident with an axis of hexagonal or trigonal symmetry. This will separate the forms into two divisions: the **Hexagonal** and the **Rhombohedral** or **Trigonal.**

a. The Hexagonal Division comprises the Holohedral Forms, the Pyramidal Group, the Hexagonal Trapezohedrons, and the Iodyrite and Nephelite Types.

b. The Trigonal Division comprises the Rhombohedral Group, the Ditrigonal Pyramids, the Tetartohedral Forms, and the Tourmaline and Sodium-Periodate Types.

4. Note the dominant and modifying forms in the order of their importance.

5. Select and name the planes belonging to each form.

6. Distinguish the holohedral, hemihedral, tetartohedral and hemimorphic forms, giving to each its appropriate name.

7. Locate the planes, the remaining axes, and the centers of symmetry.

CHAPTER VII

ISOMETRIC SYSTEM

THIS system derives its name from the Greek *Isos*, "equally distributed," and *Metron*, "measure or proportion," because along its axes its measurements are equal and the holohedral forms are equally proportioned. In this system, then, the three axes are of equal length and the angles are all right angles, consequently there can be no dominant unequal direction or directions. See Fig. 5.

NOMENCLATURE

Since the axes are all equal, the semi-axes can each be represented by a; and since any one of them can be selected as a vertical semi-axis and the others as lateral semi-axes, the a is in many cases omitted, the parameters only being written.

As in the other systems having three axes, a plane may intersect one, or two, or three axes; and to locate the axes in any Isometric form they must be so placed that their directions will form right angles with one another and that their lengths will be equal.

The nomenclature in this system is somewhat ex-

tensive and complicated, although not so difficult as is that of the Hexagonal System.

DISTINGUISHING CHARACTERISTICS OF THE ISOMETRIC CRYSTALS

The **Isometric** crystals are distinguished by the possession of three equal dimensions at right angles to one another, and by the further fact that these directions are always, not only crystallographic axes, but also axes of symmetry. These axes of symmetry are either tetragonal or binary. In the Holohedral forms and in the Pentagonal Icositetrahedrons the crystallographic axes are axes of tetragonal symmetry; but in the Hemihedral and Tetartohedral forms the crystallographic axes are axes of binary symmetry. This equality of dimensions gives to all the Isometric forms, especially the holohedral ones, an appearance of having been inscribed in a sphere. See Figs. 12, 15, 17, 52, 53, 56–58 and 328–445.

FORMS OF THE ISOMETRIC SYSTEM

I. **Holohedral Forms**:

1. Hexahedron or Cube.
2. Dodecahedron or Rhombic Dodecahedron.
3. Tetrakis Hexahedron or Tetrahexahedron.
4. Octahedron.

5. Trigonal Triakis Octahedron, or Triakis Octahedron, or Pyramid Octahedron, or Trisoctahedron.
6. Tetragonal Triakis Octahedron, or Icositetrahedron, or Trapezohedron.
7. Hexakis Octahedron or Hexoctahedron.

II. **Hemihedral Forms**:

A. Oblique Hemihedral Forms:

1. Tetrahedron:
   - **a.** Positive.
   - **b.** Negative.
2. Tetragonal Triakis Tetrahedron, or Tetragonal Tristetrahedron, or Deltoid Dodecahedron, or Tristetrahedron:
   - **a.** Positive.
   - **b.** Negative.
3. Trigonal Triakis Tetrahedron, Triakis Tetrahedron, or Trigonal Tristetrahedron, Pyramid Tetrahedron, or Trigon-Dodecahedron:
   - **a.** Positive.
   - **b.** Negative.
4. Hexakis Tetrahedron or Hextetrahedron:
   - **a.** Positive.
   - **b.** Negative.

B. Parallel Hemihedral Forms:

1. Pentagonal Dodecahedron or Pyritohedron:
   - a. Positive.
   - b. Negative.
2. Dyakis Dodecahedron or Diploid:
   - a. Positive.
   - b. Negative.

C. Gyroidal or Plagihedral Hemihedral Forms:

1. Pentagonal Icositetrahedron or Gyroid:
   - a. Right-handed.
   - b. Left-handed.

III. Tetartohedral Forms:

1. Tetrahedral Petagonal Dodecahedron:
   - a. Positive.
     - *u.* Right-handed.
     - *w.* Left-handed.
   - b. Negative.
     - *x.* Right-handed.
     - *z.* Left-handed.

I. HOLOHEDRAL FORMS

Given three equal axes at right angles to one another, it is our first task to see how many complete forms can be produced by arranging all the planes we can in all possible positions about these axes.

1. Let the plane intersect one axis and be parallel

to the other two, so that its symbol will be $1 : \infty : \infty$. If we take our model of the Isometric axes (see Fig. 5) and place our glass plate or piece of cardboard upon it so that it will intersect one axis and be parallel to the other two, we find that there are just six positions in which the plane can be so put as to fulfil these requirements; one at each end of the semi-axes.

If, then, planes be placed in these positions and be so cut that their edges will exactly join and make a complete form, we shall have a figure of six equal sides, which are all at right angles to one another, or a form that is called a **Hexahedron** (Greek, *Hex* and *Hedra*, which are defined on pages 18 and 33). We are all familiar with this form under its common nickname, the **Cube**. See Figs. 328, 336 and 387.

2. The next possible variation is when the planes cut two axes equally and are parallel to the third axis; its symbol is $1 : 1 : \infty$. By placing the trial plate about the axes in all the different positions in which it will fulfil the necessary requirements, one can ascertain that there are just twelve different positions in which the plane can be placed. These positions are such that the plane can join the ends of two of the semi-axes and still be parallel to the third axis. If enough planes are placed in these positions and extended until they meet, a twelve-sided figure or **Dodecahedron** will be produced. This is sometimes

called the Rhombic Dodecahedron, to distinguish it from the other Dodecahedrons. The name comes from the Greek, *Dodeka*, "twelve," and *Hedra*, see page 23. See Fig. 329.

3. The next variation in the position of our plane will be to have it cut two of the axes unequally and still remain parallel to the third axis; its symbol is $1 : m : \infty$. By placing our plate in all the different positions in which it can be located about the Isometric axes and still fulfil the above requirements, we ascertain that there are twenty-four such positions. If we put these twenty-four planes about the axes so that each face will cut one axis at unity and the next at some greater distance, m, and will be parallel to the third axis, then we find that each Hexahedron or Cube face has been replaced by a pyramid formed by four triangles ($6 \times 4 = 24$).

From this combination we obtain the name **Tetrakis Hexahedron,** which is derived from the Greek *Tetrakis*, "four times," combined with *Hexahedron*, the derivation of which has already been explained (see p. 126). The faces, then, are four triangles taken six times, or twenty-four triangles. See Fig. 330.

4. The next most simple variation is to place the plane so as to cut all three axes equally; its symbol is $1 : 1 : 1$.

In this case it will be found that there are eight

positions in which the plane can be located upon the axes in such a manner as to fulfil the requirements above given. The placing of eight planes so as to intersect all the axes equally, and their extension until they join and make a complete form, will give rise to the figure known as the **Octahedron** or **Regular Octahedron,** whose faces are composed of eight equilateral triangles, and whose name comes from the Greek, *Okto*, "eight," and *Hedra*, see page 23. See Figs. 12, 338, 339.

5. The next variation is to have the plane cut two axes equally, and the third axis at some greater distance, m. The symbol is $1 : 1 : m$.

By arranging our plate in as many positions as possible about the axes, and still making it agree with the above variation, we shall find that for each octahedral face there are three positions that answer, or twenty-four planes. If these twenty-four planes are put in position and extended until they all meet to form a complete whole, it is found that all the faces are triangles. Thus it is seen that the form is composed of three triangles multiplied by the complete number of octahedral faces (8), or twenty-four triangles. Hence the name **Trigonal Triakis Octahedron,** meaning a form whose faces are made by eight times three triangles. This is taken from the Greek *Triakis*, thrice; see also pages 19, 23, and 128. The name is

often abbreviated as the **Trisoctahedron**; again, the form is occasionally denominated the *Pyramid Octahedron*, because each octahedral face is replaced by a triangular pyramid whose faces are triangles. See Fig. 331.

6. The next variation is to have the plane cut one axis at unity and the other axes at a greater distance, which shall be equal for both these axes. The symbol is $1 : m : m$.

If we place the plate upon the axes so as to find how many different positions there are in which it can be put and still fulfil the above requirements, it will be seen that there are twenty-four. If we place twenty-four planes in these positions and extend them so that they will meet and make a complete figure, it will be seen that the complete figure is composed of twenty-four tetragons; *i. e.*, three tetragons replacing each octahedral face. See Figs. 332 and 333.

The name **Tetragonal Triakis Octahedron** is derived from the Greek, see pages 18, 23 and 128. Other names given to it are the **Trapezohedron**, because each face is a trapezium; **Leucitohedron** or **Leucitoid**, because the mineral Leucite crystallizes in this form; and **Icositetrahedron** from the Greek *Eikosi*, "twenty," *Tetra* (in composition) see page 18, and *Hedra*, see page 23.

7. The next and last possible variation is when the

plane cuts all three axes at unequal distances; its symbol is $1 : m : n$.

Placing the plate upon the axes so that it will cut all three unequally, we find that there are forty-eight positions in which the above requirements will be fulfilled, or six for every octahedral face; hence the name **Hexakis Octahedron,** which is often shortened to **Hexoctahedron,** from the Greek *Hexakis* "six times," the entire name signifying "six times eight faces," or the "forty-eight-faced form." It is often nicknamed the **Adamantoid** because the Diamond (Greek *Adamas*, "adamant") crystallizes in this form. See Figs. 334 and 335.

The holohedral forms have *nine planes of symmetry*. *Three* of these form right angles with one another and are coincident with the planes of the crystallographic axes. The other *six planes of symmetry* unite the diagonally opposite edges of the cube and, in the center, are coincident with one axis and make angles of 45° with the other two. Since, in the other holohedral forms, they of necessity occupy the same position that they do in the cube, they can be easily located by comparing the other forms with a cube.

There are also *three axes of tetragonal symmetry* that coincide with the crystallographic axes (cubic axes); *four axes of trigonal symmetry* (octahedral axes) that join the diagonally opposite corners of the cube; and

lastly, *six axes of binary symmetry* that join the centres of the diagonally opposite edges of the cube (dodecahedral axes). It can be seen that the axes of tetragonal symmetry lie in the chief planes of symmetry, bisecting them; and that the axes of binary symmetry lie in the other six planes of symmetry, bisecting them. There is also a center of symmetry.

As a matter of convenience, the above axes of symmetry are also considered as crystallographic axes and are used in descriptions and in calculations.

1. The three crystallographic axes proper of this system are called **Cubic** because they are perpendicular to the faces of the cube. See *a*, *a*, Fig. 336.

2. The four axes that join the diagonally opposite corners of the cube are designated as **Octahedral** because they are perpendicular to the faces of the octahedron. See *b*, *b*, Fig. 336.

3. The six axes that join the centers of diagonally opposite corners of the cube are called **Dodecahedral** because they are perpendicular to the faces of the dodecahedron. See *c*, *c*, Fig. 337.

II. HEMIHEDRAL FORMS.

A. **Oblique Hemihedral Forms**:

These forms are called *oblique* because the faces are not parallel to one another, but are always so arranged that they form oblique angles with each other. See Figs. 338–353.

1. The **Tetrahedron** can be regarded as produced by extending, until they meet, the alternate upper and lower planes of the octahedron, and by suppressing the other alternate planes. This operation causes the apices of the octahedron to be prolonged into an edge, and yields a four-faced wedge-shaped figure formed of equilateral triangles, and named **Tetrahedron,** from the two Greek words *Tetra* and *Hedra,* which have previously been defined (see pages 18 and 23). Its symbol in the Weiss notation is $\frac{1}{2}$ (1 : 1 : 1), the parentheses being used to denote **Oblique Hemihedral Forms.** See Figs. 338 and 339.

If the planes that were considered suppressed are extended and those formerly extended are suppressed, another form results, composed of the other half of the octahedron. Singly, one tetrahedron differs in no way from the other, except in its position. In combination, the planes of one modify the solid angles of the other, and they are distinguished from each other as **Positive** and **Negative.** See Figs. 340 and 341.

If the tetrahedron is so placed that one edge is horizontal and parallel to the observer, then the form can be called **Positive.** If another tetrahedron is so placed that its horizontal edge is pointing towards the observer, the form is **Negative.**

2. The **Tetragonal Triakis Tetrahedron** may be considered as formed by the extension of the alternate

upper and lower sets of three triangular faces, which occupy, in the trigonal triakis octahedron, the positions of the alternate faces of the octahedron, and by the suppression of the other alternate sets of three planes. When the faces thus extended are carried out so as to make a complete form, it will be found that each face is not a triangle, as in its original form, but is now a tetragon. See Figs. 342–345.

The completed form is called **Tetragonal Triakis Tetrahedron,** i. e., four times three tetragonal faces, a name derived from the Greek, see pages 18, 128, and 132. This is often abbreviated as the **Tristetrahedron.** Its symbol is $\frac{1}{2}$ (1: 1: *m*). There are two forms to be produced by varying the sets of faces that are to be extended or to be suppressed, or the **Positive** and **Negative.** The tetrahedral edge, instead of being straight, is broken and formed by two lines. If this broken edge is placed parallel to the observer, the form can be called **Positive:** but if it is directed towards the observer, it is considered as **Negative.** See Figs. 344 and 845.

3. The **Trigonal Triakis Tetrahedron** may be considered as produced by the extension of the alternate upper and lower sets of three tetragons that occupy the place of the octohedral faces in the tetragonal triakis octahedron, and by the suppression of the other alternate sets. When the extended faces are carried

out so as to meet, the original tetragons become triangles, and the figure is composed of four times three triangular faces. See Figs. 346–349.

The name **Trigonal Triakis Tetrahedron** is derived from the Greek, see pages 19, 128, and 132. Its symbol is $\frac{1}{2}$ (1: m: m). As before, there are two forms, **Positive** and **Negative.** The tetrahedral edge in this form is a straight line. If this be placed parallel to the observer, then the form can be considered **Positive** but if this edge is directed towards the observer, the form is **Negative.** See Figs. 348, 349. The name is often abbreviated as the **Trigonal Tristetrahedron.**

The student should always remember that the hemihedral form of the *Trigonal Triakis Octahedron* is the **Tetragonal Triakis Tetrahedron,** and that of the *Tetragonal Triakis Octahedron* is the **Trigonal Triakis Tetrahedron.** See Figs. 344 and 348.

4. The **Hexakis Tetrahedron,** or, as abbreviated, the **Hextetrahedron,** can be considered to be derived from the extension of the upper and lower alternate sets of six triangles that occupy the position of the octahedral faces in the hexakis octahedron, and by the suppression of the other sets of alternate faces. See Figs. 350 and 351. This procedure leads to the production of six triangles in the position of each tetrahedral face, or four times six, a fact which gives to the form its name **Hexakis Tetrahedron** (from the Greek, see pages 130

and 132). This form may be either **Positive** or **Negative.** Its tetrahedral edge is formed by two broken lines. If the form is so placed that its upper tetrahedral edge runs parallel to the observer, the form is **Positive**; but if this edge is directed towards the observer, it is **Negative.** Its symbol is $\frac{1}{2}(1 : m : n)$. See Figs. 352 and 353.

The **Oblique Hemihedral forms** have *six planes of symmetry* which lie parallel to the faces of the dodecahedron; *i. e.*, each one lies parallel to one tetrahedral edge, and is perpendicular to and bisects the opposite tetrahedral edge.

These forms have *four axes of trigonal symmetry* that extend perpendicularly from each solid tetrahedral angle to the opposite tetrahedral face in the tetrahedron (octahedral axes); and which of course occupy the same positions in the other oblique hemihedral forms. They also have three axes of binary symmetry coincident with the crystallographic axes, but have no center of symmetry.

B. **Parallel Hemihedral Forms.**

These forms are called *parallel,* because every plane has an opposite plane that is parallel to it. See Figs. 52, 53, 136, 137 and 356–359.

The **Pentagonal Dodecahedron** may be considered to be formed from the tetrakis hexahedron by the ex-

tension of one pair of planes touching at their apices, in each set of four triangles which replace the faces of the hexahedron, and by the suppression of the other pair. If we do this for each replaced hexahedral face, taking care to alternate the pairs so that no two extended or two suppressed planes join base to base, a twelve-faced figure results, whose face is a pentagon or has five sides; four of these are equal, while the fifth is bisected by the termination of a crystallographic axis, and is of unequal length as compared with the other four sides. See Figs. 354–359.

As the form is composed of twelve pentagons, it is called the **Pentagonal Dodecahedron** (from the Greek, *pente*, "five," compounded with other Greek words that have been defined on pages 18 and 127). It is also commonly nicknamed **Pyritohedron,** which may be freely translated as the Pyrite-faced-figure, because the mineral Pyrite often crystallizes in this form.

The symbol is $\frac{1}{2}[1 : m : \infty]$; the brackets are used to distinguish parallel-faced forms in the Weiss system.

By extending the planes previously suppressed, and by suppressing those previously extended, another Pentagonal Dodecahedron results, which in no way differs from the preceding, except in the position of its axes. The first is known as **Positive** and the second as **Negative.** If the forms are so placed that one crystallographic axis is perpendicular, and if the edge

bisected by that axis is parallel to the observer, the form in question is **Positive**; but if it is directed towards the observer, then it is **Negative**. Again if the axis is horizontal and directed towards the observer, and if the edge nearest him is perpendicular, the crystal is positive; but if that edge is horizontal, the form is negative. See Figs. 52, 53, 356 and 357.

2. The **Dyakis Dodecahedron** can be considered to be formed by extending each set of two planes of the hexakis octahedron which answer to each plane of the Tetrakis Hexahedron that was extended or suppressed to form the Pentagonal Dodecahedron. If, then, each set of planes be extended or suppressed as was done in the preceding case, two forms result, **Positive** and **Negative**, each made up of twenty-four faces that are trapeziums. See Figs. 136, 137 and 360–364. If a Dyakis Dodecahedron be placed with an axis vertical and if the broken edge that answers to the edge of the Pentagonal Dodecahedron runs parallel to the observer, then the form is **Positive**; but if it extends towards the observer, then the form is considered to be **Negative**. See Figs. 136, 137 and 362–364. The name Dyakis Dodecahedron or Didodecahedron is derived from the Greek, *Dyakis*, or *Dis*, "twice or double," united with other Greek words that have been given on pages 23 and 127, meaning a double dodecahedron or twenty-four-faced figure. It is often

nicknamed the **Diploid** (from the Greek *Diplos*, "two-fold or double" and *oid*, see page 11). Haidenger, who gave the form this name, states, in substance, that he does so because of the peculiar arrangement of its surface into three pairs of double twin planes ($3 \times 2 \times 2 \times 2 = 24$). Its symbol is $\frac{1}{2}[1 : m : n]$.

The **Parallel Hemihedral** forms possess *three planes of symmetry* forming right angles with one another, and coinciding with the planes of the crystallographic axes. These forms also have *four axes of trigonal symmetry* that join the diagonally opposite triedral solid angles in the Dyakis Dodecahedron (octahedral axes) and also the triedral solid angles that occupy the same position in the Pentagonal Dodecahedron. The three crystallographic axes (cubic axes) are here *axes of binary symmetry.* There is also a center of symmetry.

C. **Gyroidal Plagiohedral** or **Hemihedral Forms.**

1. The **Pentagonal Icositetrahedron** may be considered to be formed by the extension of the alternate planes of the hexakis octahedron until they meet and by the suppression of the other set of alternate planes. By reversing this process another twenty-four-faced figure will result. Thus there are two forms known as **Right-handed** and **Left-handed.** See Figs. 365–367.

These two forms can be distinguished by placing one axis perpendicular to the observer and one pointing directly towards him. Let him look at the edge that begins at the top of the vertical axis and runs most nearly parallel with the axis pointing towards him. If that edge inclines towards the right of the axis the form is **Right-handed,** but if it inclines to the left of the axis it is **Left-handed.** In the case of many figures and also in some models the forms are interchanged.

The faces of these forms are all similar irregular pentagons, and the forms are called **Icositetrahedrons** (see page 129). This is also nicknamed the **Gyroid** (from the Greek *Gyros,* "round, bent, curved or arched"), because the planes are arranged in an irregular circular order about the crystal.

The Pentagonal Icositetrahedrons have neither planes nor center of symmetry. They do have *three axes of tetragonal symmetry* coincident with the crystallographic (cubic) axes, *four axes of trigonal symmetry* coincident with the octahedral axes, and *six axes of binary symmetry* coincident with the dodecahedral axes, or they have all the axial symmetry of the holohedral forms.

III. TETARTOHEDRAL FORMS.

1. The **Tetrahedral Pentagonal Dodecahedron,** or the **Tetartoid,** may be considered to be formed by the extension of every set of three alternate planes amongst every set of six that replaced the tetrahedral faces in the hexakis tetrahedron, and by the suppression of the other sets of three. By doing this one obtains a twelve-faced figure of a tetrahedral form with three irregular pentagonal faces replacing each tetrahedral face. By the alteration of the extended and suppressed faces, two forms, Right-handed and Left-handed, result from each hexakis tetrahedron. Since there are two hexakis tetrahedrons, or a positive and a negative form, there will be four of these tetartohedral forms:

a. Positive:
- *u.* Right-handed.
- *w.* Left-handed.

b. Negative:
- *x.* Right-handed.
- *z.* Left-handed.

Let the student place the **Tetrahedral Pentagonal Dodecahedron** with the broken line (composed of three zigzag lines, and corresponding to the edge of a tetrahedron) approximately horizontal and parallel to himself. If, then, the upper right-hand plane of the three

next to him lie with its longest direction nearly horizontal, the crystal is **Positive**; but if the same plane has its longest direction standing nearly vertical, the crystal is **Negative**. See Figs. 369 and 370.

The **Tetrahedral Pentagonal Dodecahedrons** have neither *planes of symmetry* nor any *center of symmetry*. They have *four axes of trigonal symmetry* that join the acute triedral solid angles with the opposite obtuse triedral solid angles; or, in other words, they are perpendicular to the faces of a tetrahedron. The crystallographic (cubic) axes are coincident with *three axes of binary symmetry*.

COMPOUND FORMS.

Single forms are common in the Isometric system, but the union of two or more forms in a single crystal is the more general rule, as it is in the other systems, and they are associated as follows:

1. The **Holohedral Forms** can all combine with one another. See Figs. 15, 17, 56–58, and 371–400.

2. The **Oblique Hemihedral Forms** can combine with one another and with the *Cube, Dodecahedron,* and *Tetrakis Hexahedron,* but are never united with the *Parallel Hemihedral Forms.* See Figs. 401–423.

3. The **Parallel Hemihedral Forms** can combine with one another and with the *Cube, Dodecahedron, Trigonal Triakis Octahedron,* and *Tetragonal Triakis Octahedron.* See Figs. 424–445.

4. The **Pentagonal Icositetrahedrons** or **Gyroids** can combine with each other or with the *Cube, Dodecahedron, Tetrakis Hexahedron, Octahedron, Trigonal Triakis Octahedron*, and *Tetragonal Triakis Octahedron.*

5. The **Tetrahedral Pentagonal Dodecahedrons** can combine with one another and with the *Cube, Dodecahedron, Pentagonal Dodecahedron, Tetrahedron, Tetragonal Triakis Tetrahedron* and *Trigonal Triakis Tetrahedron.*

RULES FOR NAMING ISOMETRIC PLANES.

In this system the distinction of the planes of one form from those of another is accomplished most easily by the use of the parameters. If the student has located the axes correctly and determined the parameters of a plane, and if he remembers the name of the form that has these parameters, he can at once designate the form to which the plane belongs. He need pay no attention to the size or shape of the plane; for its relation to the axes and the number of similar planes making the complete form are the only points with which he is concerned. If he understands the above statement, he can name any plane in this system by the following rules:

I. If the plane cuts one axis at unity and is parallel to the other two, that is, if its symbol is $1 : \infty : \infty$, the plane belongs to a **Cube**.

II. If the plane cuts two axes at unity and is parallel to the other one, that is, if its symbol is $1 : 1 : \infty$, the plane belongs to a **Dodecahedron.**

III. If the plane intersects two of the axes unequally and is parallel to the third axis, that is, if its symbol is $1 : m : \infty$, the plane belongs to one of two forms:

a. If the form has the complete number of planes (24), then the plane belongs to a **Tetrakis Hexahedron.**

b. If the form has one-half the complete number of planes (12), then the plane belongs to a **Pentagonal Dodecahedron.**

IV. If the plane cuts all three axes at unity, that is, if its symbol is $1 : 1 : 1$, it may belong to one of two forms:

a. If the form has the complete number of planes (8), then the plane belongs to an **Octahedron.**

b. If the form has half the complete number of planes (4), then it belongs to a **Tetrahedron.**

V. If the plane intersects two axes at unity and the third axis at a greater distance, that is, if its symbol is $1 : 1 : m$, it belongs to one of two forms:

a. If the form has the complete number of planes (24), then the plane belongs to a **Trigonal Triakis Octahedron.**

b. If the form has one-half the complete number of planes (12), then the plane belongs to a **Tetragonal Triakis Tetrahedron.**

VI. If the plane cuts one axis at unity and intersects the other two axes at a distance which is greater than unity, but which is equal for both axes, that is, if its symbol is $1 : m : m$, the plane may belong to one of two forms:

a. If the form has the complete number of planes (24), then the plane belongs to a **Tetragonal Triakis Octahedron.**

b. If the form has half the complete number of planes (12), then the plane belongs to a **Trigonal Triakis Tetrahedron.**

VII. If the plane cuts all three axes unequally, that is, if its symbol is $1 : m : n$, the plane may belong to one of four forms:

a. If the form has the complete number of faces (48), then the plane belongs to a **Hexakis Octahedron.**

b. If the form has half the complete number of planes (24), it may belong to one of two forms:

1. If the opposite planes form oblique angles with each other, the planes belong to a **Pentagonal Icositetrahedron** or **Gyroid.**

2. If the opposite sides are parallel, the planes belong to a **Dyakis Dodecahedron** or **Diploid.**

c. If the form has one-fourth the complete number of planes (12), the planes belong to a **Tetragonal Pentagonal Dodecahedron.**

READING DRAWINGS OF ISOMETRIC CRYSTALS

Since in this system all the semi-axes or parameters are equal, a is the symbol used to designate each semi-axis, and any plane cutting all the axes equally would have as its symbol $1a : 1a : 1a$; but there is apparently no advantage in keeping the a, and our symbol can as well be written $1 : 1 : 1$. As a matter of convenience, the a is dropped in this text, but it is retained in most crystallographies in which the Weiss notation is used. The a can readily be supplied in the notation if one desires to employ the more common form of the Weiss symbols.

The other symbols follow so closely those which have been given in the other systems that the student should have no difficulty in understanding them.

As stated on pages 37 and 111, Greek letters are used to designate the various partial forms in the Miller notation. In the following table, κ is used to designate in that notation the oblique Hemihedral forms; π, to indicate the Parallel Hemihedral forms; γ, to mark the Pentagonal Icositetrahedrons; and $\kappa\pi$, to point out the Tetartohedral forms.

While italic letters are used in crystallographic symbols in most cases, in some publications, particularly in a few recent text-books, the common type is employed.

TABLE VI

ISOMETRIC FORMS AND NOTATIONS

Forms.	Weiss.	Naumann.	Dana.	Miller.
Hexahedron or Cube.	$1:\infty:\infty$	$\infty O \infty$	i-i or a	100
Dodecahedron	$1:1:\infty$	∞O	i or d	110
Tetrakis Hexahedron.	$1:m:\infty$	$\infty O m$	i-m	$hk0$
Octahedron.	$1:1:1$	O	1 or o	111
Trigonal Triakis Octahedron.	$1:1:m$	mO	m	hhl
Tetragonal Triakis Octahedron.	$1:m:m$	mOm	m-m	hll
Hexakis Octahedron.	$1::m:n$	mOn	m-n	hkl
Tetrahedrons.	$\frac{1}{2}(1:1:1)$ $-\frac{1}{2}(1:1:1)$	$\frac{O}{2}$ $-\frac{O}{2}$	$\frac{1}{2}(1)$ $-\frac{1}{2}(1)$	$\kappa\{111\}$ $\kappa\{1\bar{1}1\}$
Tetragonal Triakis Tetrahedrons.	$\frac{1}{2}(1:1:m)$ $-\frac{1}{2}(1:1:m)$	$\frac{mO}{2}$ $-\frac{mO}{2}$	$\frac{1}{2}(m)$ $-\frac{1}{2}(m)$	$\kappa\{hhl\}$ $\kappa\{h\bar{h}l\}$
Trigonal Triakis Tetrahedrons.	$\frac{1}{2}(1:m:m)$ $-\frac{1}{2}(1:m:m)$	$\frac{mOm}{2}$ $-\frac{mOm}{2}$	$\frac{1}{2}(m\text{-}n)$ $-\frac{1}{2}(m\text{-}n)$	$\kappa\{hll\}$ $\kappa\{h\bar{l}l\}$
Hexakis Tetrahedrons.	$\frac{1}{2}(1:m:n)$ $-\frac{1}{2}(1:m:n)$	$\frac{mOn}{2}$ $-\frac{mOn}{2}$	$\frac{1}{2}(m\ n)$ $-\frac{1}{2}(m\text{-}n)$	$\kappa\{hkl\}$ $\kappa\{h\bar{k}l\}$
Pentagonal Dodecahedrons.	$\frac{1}{2}(1:m:\infty)$ $-\frac{1}{2}(1:m:\infty)$	$\left[\frac{\infty Om}{2}\right]$ $-\left[\frac{\infty Om}{2}\right]$	$\frac{1}{2}(i\text{-}m)$ $-\frac{1}{2}(i\text{-}m)$	$\pi\{hk0\}$ $\pi\{kh0\}$

TABLE VI—*Concluded*

Forms.	Weiss.	Naumann.	Dana.	Miller.
Dyakis Dodecahedrons.	$\frac{1}{2}\ 1 : m : n$	$\left[\frac{mOn}{2}\right]$	$\frac{1}{2}(m\text{-}n)$	$\pi\{hkl\}$
	$-\frac{1}{2}\ 1 : m : n$	$-\left[\frac{mOn}{2}\right]$	$-\frac{1}{2}(m\text{-}n)$	$\pi\{khl\}$
Pentagonal Icositetrahedrons.	$\frac{1}{2}(1 : m : n)r$	$\frac{mOn}{2}r$	$\frac{1}{2}(m\text{-}n)r$	$\gamma\{hkl\}$
	$-\frac{1}{2}(1 : m : n)l$	$\frac{mOn}{2}l$	$\frac{1}{2}(m\text{-}n)l$	$\gamma\{lkh\}$
Tetrahedral Pentagonal Dodecahedrons.	$\frac{1}{4}(1 : m : n)r$	$\frac{mOn}{4}r$	$\frac{1}{4}(m\text{-}n)r$	$\kappa\pi\{hkl\}$
	$\frac{1}{4}(1 : m : n)l$	$\frac{mOn}{4}l$	$\frac{1}{4}(m\text{-}n)l$	$\kappa\pi\{lkh\}$
	$-\frac{1}{4}(1 : m : n)r$	$-\frac{mOn}{4}r$	$-\frac{1}{4}(m\text{-}n)r$	$\kappa\pi\{lkh\}$
	$-\frac{1}{4}(1 : m : n)l$	$-\frac{mOn}{4}l$	$-(\frac{1}{4}m\text{-}n)l$	$\kappa\pi\{h\bar{k}l\}$

DIRECTIONS FOR STUDYING ISOMETRIC CRYSTALS

1. Prove that the crystal is Isometric by finding that it has three equal directions at right angles to one another. These directions coincide with the crystallographic axes and with the axes of tetragonal or binary symmetry.

2. Note the dominant and modifying forms in the order of their importance.

3. Determine the parameters (i. e., the symbol) of each set of similar planes, and from the parameters name the forms in accordance with the rules, distinguishing the holohedral, hemihedral, and tetartohedral forms.

4. Locate the planes, axes, and centers of symmetry.

CHAPTER VIII

MINERAL AGGREGATES, PARALLEL GROWTHS, AND TWINS

A. Minerals are either **Crystalline** or **Amorphous**, from the Greek *a*, "without," and *Morphe*, "form." When **Crystalline** they show an internal crystalline structure, and may or may not possess a more or less perfect crystal form.

When **Amorphous** they have neither a regular external form nor any internal crystalline structure. The only apparent exception is when percolating waters or other agents remove the original material partially or entirely and replace it by other materials, which assume the form of the mineral it has replaced. For example, a crystal of pyrite is often replaced by the amorphous limonite, which keeps the outlines of the original pyrite crystal; something like a wolf in sheep's clothing. Minerals when they masquerade in the form belonging to other minerals are said to be **Pseudomorphs**, from the Greek *Pseudes*, "false," and *Morphe*, "form."

B. COMPOUND MINERALS OR CRYSTALS

It is usual to find minerals grown together or united either *regularly* or according to some law, or else *irregularly* or without regard to any apparent law.

I. A **Mineral Aggregate** is formed by the *irregular union* of many minerals. The minerals composing the *Aggregate* are generally imperfect crystals, and hence the *Mineral Aggregate* can often be justly styled a *Crystalline Aggregate.* See Fig. 446.

II. When the minerals joined together are so arranged that similar parts are parallel they are called **Parallel Growths** or **Parallel Groups.** See Figs. 23–27, 447–457. There may be two divisions of these growths: **1.** When all the parts of a crystal are parallel to all the similar parts of the conjoined crystals. **2.** When one part of a crystal is parallel to the similar parts of its attached crystals.

III. When the two parts of a crystal are joined so that by revolving one part 180 degrees it will form with the other part a simple crystal, the crystal is said to be a **Twin.** That is to say one part occupies a reverse position relative to the other part, so that by turning one of the parts half way around a simple crystal will result. See Figs. 463–579.

In ordinary language the term *twin* refers to two only but in Crystallography it relates to two or more

forms joined together by crystallographic planes. When the twinned form is composed of three individual crystals united, the individuals can be spoken of as *twins* or as *trillings*. See Figs. 517, 565, 567. If there are four or five individuals, then the twins can be designated as *fourlings* or *fivelings;* if there are eight individuals, then the twins can be called *eightlings;* and so on.

C. *Mineral Aggregates, Parallel Growths,* and *Twinned Crystals* form **Reentrant Angles.** See Figs. 458, 461, 464, 466–468, 470, 476, 477, 479, 481–486, 488, 493–495, 498–561, 563–565, 567, 571–573.

It often happens that owing to the minuteness of he **Reentrant Angle,** or from other causes, this feature is only brought out by the minute structure of the crystals or by means of *polarized light.*

While **Reentrant Angles** are usually considered to indicate *Aggregates, Parallel Growths* or *Twins,* yet there are some exceptions; therefore every case of these angles needs to be examined for itself, to see whether it falls under the common rule or not. See Figs. 471–474.

D. Certain of the *Parallel Growths* and *Twins* are often made up partly or entirely of numerous thin plates that are arranged parallel to one another. When the plates are extremely thin, the reentrant angles often show as very *fine parallel lines* or *striations*

which look as if they had been scratched by a diamond point or a needle, something like a diffraction grating. See Figs. 452–457, 459–460, 462. In most cases they can be seen only when the mineral is held at a special angle or examined under a lens.

When the *striations* are considered to be due to the alternate formation of two different crystal faces the structure is called an **Oscillatory Combination.** It is usual to speak of the forms produced by this combination as simple or single crystals. This *Oscillation* is illustrated in the pyrite crystals, which show an *Oscillatory Combination* of the cube and pentagonal dodecahedron. See Figs. 455, 456.

When these **striations** are considered to be caused by *parallel growths* or by *repeated twinning* the structure is designated as **Polysynthetic Growths** or **Polysynthetic Twinning,** as the case may be, from the Greek *Polysynthetos* meaning "compounded of many things." See Figs. 459–462.

E. TWIN CRYSTALS

There are two different classes of twins, which, for convenience, are frequently distinguished as follows:

I. **Contact Twins.**

II. **Penetration Twins.**

These classes are so closely allied that their distinction one from the other is often difficult if not impos-

sible. Fortunately their distinction is not an important matter except in well-marked cases.

I. *Contact Twinning*

The great majority of twinned crystals are united by some crystallographic plane known as the **Composition Plane**. Such compound crystals are called **Contact Twins**. The **Composition Plane** is often, but not always, coincident with a plane known as the **Twinning Plane**. This latter plane is the plane that will separate the twinning crystal into two parts, so that if one part is revolved 180° and again joined to the other part, the union of the two parts will make a complete and symmetrical crystal form.

The axis about which one part of the crystal is to revolve 180° is known as the **Twinning Axis**. It is perpendicular to the *twinning plane*. For example, in Figs. 463, 465, 469, 471, 473 and 478, the plane a, b, c, d, e, f, is not only a *composition plane*, but also a *twinning plane;* for not only are the two parts united by it, but also if one part of Fig. 464 is revolved 180° on the other, the resulting form is the simple and complete octahedron shown in Fig. 463. The same thing can be observed in various other forms. See Figs. 466–519.

As previously stated, twin forms are often designated as *trillings, fourlings, fivelings*, etc., according to the number of individual forms. This repeated twinning takes place in two ways:

1. The twinning plane may remain parallel to itself, in which case we have the earlier described **Polysynthetic Twinning.** See page 151 and Figs. 458–461.

2. The twinning planes may change their directions, giving rise to groups that tend to assume more or less circular forms. These forms are often called **Cyclic Twins,** from the Greek *Kyklos,* "a ring, a circle, a round and circular body, a wheel, a sphere or a globe." See figs. 509–514, 516–519.

II. *Penetration Twinning*

If we imagine that one crystal can penetrate another and leave, mutually projecting from each, their solid angles, we shall have a form known as a **Penetration Twin.** In Figs. 522–530, illustrating this structure, it will be noticed that the projecting solid angles of one cube look as if they had been cemented upon the sides of another cube. By the exercise of a little imagination we can readily suppose that the lines connecting the edges of the various solid angles are produced so as to complete the cube. Figs. 520, 521, 531–556 show similar **Penetration Twins** of various other forms.

MIMICRY

The term **Mimicry** is employed to designate the condition whereby a crystal belonging to one system

may simulate the appearance of a crystal belonging to another.

Good examples of the progressive steps taken by one form *simulating* that of another, can be seen in Figs. 557–580. In Figs. 557–559 it is shown that by increasing the number of twin crystals of one system a form roughly resembling one belonging to another system is produced. In this case twinned orthorhombic crystals produce a seemingly hexagonal form.

This is observed in Aragonite as shown by Figs. 563, 551, 561, 564 and 580, which mark in the order named the progressive steps from a simple orthorhombic twin to a nearly complete hexagonal crystal. This is strikingly shown in Figs. 565 and 566 for Cerussite; and in Figs. 575–579 for Witherite. Figs. 568 and 569 show the completed **Mimicry** of a hexagonal crystal by the orthorhombic Bromelite. Figs. 560 and 562 show simulating forms of Marcasite, and Fig. 567 one for Chrysoberyl.

Figs. 570–574 show successive stages in the twinning of the monoclinic Phillipsite until it resembles an isometric dodecahedron.

By **Mimicry**, it can be seen from the above examples, that the *simulation*, as a rule, is only approximate, and often quite largely imaginary. In all cases either defects in the perfection of the form mimicked or its structure as observed in polarized light will distinguish the real form from the imitation.

CHAPTER IX

CLEAVAGE

THE **Cleavage of Minerals** is their property of splitting indefinitely parallel to certain crystal planes. In actual *cleavage* it is practically impossible to obtain *cleavage plates* so thin that they could not be split into still *thinner leaves*, provided we had the necessary mechanical means to accomplish this.

It is to be noted that *cleavage in minerals* does not run at random, but is parallel to certain crystal faces. In designating the **Cleavage** it is customary to use the name of the form to whose faces the *cleavage is parallel.* Thus, if the mineral splits parallel to the faces of an octahedron, the *cleavage* is said to be Octahedral. Again if the *cleavage* runs parallel to the plane of a cube, a dodecahedron, a pinacoid, a prism, a pyramid, or a rhombohedron, then the **Cleavage** is said to be **Cubical, Dodecahedral, Pinacoidal, Prismatic, Pyramidal,** or **Rhombohedral,** respectively. In the case of *pinacoidal cleavage* it is customary to designate the pinacoid to which the cleavage is parallel, as brachy- or clino-, or macro-, or ortho-pinacoidal or basal, ac-

cording to the pinacoid in question, whether it is a brachy-, or clino- or a macro-, or an ortho-, or a basal pinacoid.

The faces to which the *cleavage is parallel* belong to some of the simple principal or dominant forms. From this in order to indicate the *cleavage,* it is customary to use the *crystallographic shorthand* by stating that it is parallel to O, or 111, when it is octahedral; or in every case *it is usual to employ the symbols of the crystal planes that are parallel to the cleavage planes.*

The principal cleavages in each system are given below.

TRICLINIC CLEAVAGE

In the Triclinic system the cleavage is chiefly **Pinacoidal,** and less commonly **Prismatic.** The usual symbols are as follows:

1. Basal Cleavage, $0\ P$, O or c, 001.
2. Brachypinacoidal Cleavage, $\infty\ \breve{P}\ \infty$, $i\text{–}\breve{\imath}$ or b, 010.
3. Macropinacoidal Cleavage, $\infty\ \bar{P}\ \infty$, $i\text{–}\bar{\imath}$ or a, 100.
4. Hemiprismatic Cleavage $\begin{cases} \infty\ P', I' \text{ or } m, 110. \\ \infty'\ P, I \text{ or } M, 1\bar{1}0. \end{cases}$
5. Hemibrachydomatic Cleavage $\begin{cases} ,\breve{P}'\ \infty, 1\text{–}\breve{\imath}, 011. \\ '\breve{P}_{,}\ \infty, 1\text{–}\breve{\imath}', 0\bar{1}1. \end{cases}$
6. Hemimacrodomatic Cleavage $\begin{cases} '\bar{P}'\ \infty, '1\text{–}\bar{\imath}', 10\dot{1}. \\ ,\bar{P}_{,}\ \infty, ,1\text{–}\bar{\imath}_{,}, \bar{1}01. \end{cases}$

The two last cleavages are commonly grouped as **Hemidomatic.**

MONOCLINIC CLEAVAGE

In the Monoclinic System the most common cleavages are **Pinacoidal** and **Prismatic.** The chief cleavages and their symbols are as follows:

1. Basal Cleavage, $0\ P$, O or c, 001.
2. Clinopinacoidal Cleavage, $\infty\ P\ \grave{\infty}$, $i\text{–}i\grave{}$ or b, 010.
3. Orthopinacoidal Cleavage, $\infty\ P\ \bar{\infty}$, $i\text{–}\bar{\imath}$ or a, 100.
4. Prismatic Cleavage, $\infty\ P$, I or m, 110.
5. Clinodomatic Cleavage, $P\ \grave{\infty}$, 1–ì, 011.
6. Hemiorthodomatic Cleavage, $\begin{cases} P\ \bar{\infty}, 1\text{–}\bar{\imath}, 101. \\ -P\ \bar{\infty}, -1\text{–}\bar{\imath}, 101. \end{cases}$
7. Hemipyramidal Cleavage, $\begin{cases} P, 1, \bar{1}11. \\ -P, -1, 111. \end{cases}$

ORTHORHOMBIC CLEAVAGE

In the Orthorhombic system the most common cleavages are **Pinacoidal** and **Prismatic.**

The symbols and most cleavages in this system are:

1. Basal Cleavage, $0P$, O or c, 001.
2. Brachypinacoidal Cleavage, $\infty\ \breve{P}\ \infty$, $i\text{–}\breve{\imath}$ or b, 010.
3. Macropinacoidal Cleavage, $\infty\ \bar{P}\ \infty$, i–ī or a, 100.
4. Prismatic Cleavage, $\infty\ P$, I or m, 110.
5. Brachydomatic Cleavage, $\breve{P}\infty$, 1–ĭ, 011.
6. Macrodomatic Cleavage, $\bar{P}\infty$, 1–ī, 101.

TETRAGONAL CLEAVAGE

In the Tetragonal system the common cleavages

are **Pinacoidal** and **Prismatic**, with the more rarely occurring **Pyramidal**. Their symbols are as follows:

1. Basal Cleavage, $0P$, O or c, 001.
2. Primary Prismatic Cleavage, ∞P, I or m, 110.
3. Secondary Prismatic Cleavage, $\infty P \infty$, i–i or a, 100.
4. Primary Pyramidal Cleavage, P, 1, 111.
5. Secondary Pyramidal Cleavage, $2 P \infty$, 2–i, 201.

The second and third cleavages are usually united under the general name **Prismatic**; the fourth and fifth are commonly united under the general term **Pyramidal**.

HEXAGONAL CLEAVAGE

In the Hexagonal System the more common cleavages are **Pinacoidal**, **Prismatic**, and **Rhombohedral**. The chief cleavages with their symbols are as follows:

1. Basal Cleavage, $0\ P$, O or c, 0001.
2. Primary Prismatic Cleavage, $\infty\ P$, I or m, $10\bar{1}0$.
3. Secondary Prismatic Cleavage, $\infty\ P\ 2$, i–2 or a, $11\bar{2}0$.
4. Primary Pyramidal Cleavage, P, 1, $10\bar{1}1$.
5. Secondary Pyramidal Cleavage, $P\ 2$, 1–2, $11\bar{2}2$.
6. Rhombohedral Cleavage, R, 1, $\kappa \{ 10\bar{1}1 \}$ or $10\bar{1}1$.

As in the Tetragonal System, the second and third cleavages are united under the general term **Prismatic**, and the fourth and fifth cleavages are coupled together as **Pyramidal**.

ISOMETRIC CLEAVAGE.

In the Isometric System the cleavages are **Cubic, Dodecahedral,** and **Octahedral.** Their symbols are as follows:

Cubic Cleavage, $\infty\ O\ \infty$, i–i or a, 100.

Dodecahedral Cleavage, $\infty\ O$, i or d, 110.

Octahedral Cleavage, O, 1 or o, 111.

PARTINGS

In nature crystals are often subjected to pressure that gives rise to a platy structure. The plates thus produced are usually taken for cleavage *laminae.* Since these **Parting Planes** are parallel to crystallographic planes, the same symbols are given to them as to those of the cleavage planes; that is, the symbol is that of the *crystallographic plane* to which the **Parting** is parallel.

Since the parting planes have been produced by pressure and the consequent slipping of the mineral particles on one another, a *parting structure* can be distinguished from true *cleavage structure* by the fact that the portion of the mineral lying between two adjacent planes of parting shows no tendency to split parallel to those planes. In the mineral cleavage there is a tendency on the part of the mineral to split indefinitely along planes parallel to the obvious cleavage planes.

There is thus, on the one hand, a resemblance be-

tween *mineral parting* and *parallel rock jointing;* and, on the other hand, a similar resemblance between *mineral cleavage* and *rock* or *slaty cleavage.*

The part between any two *cleavage planes* in a rock or mineral *tends to split indefinitely parallel to those planes;* but in the case of *rock jointing* or *mineral parting* there is *no tendency for the rock or mineral between two adjacent planes to split parallel to those planes.*

To a certain degree the resemblance extends to the origin of each; as both *parallel rock jointing* and *mineral parting* appear to be largely due to pressure and torsion, and are produced subsequently to the formation of the rock or mineral. On the other hand *mineral cleavage* is probably due to the molecular structure of the crystal or to its mode of chemical formation, and is congenital or was produced in the crystal when it was formed; while *rock* or *slaty cleavage* seems to be caused in nature by pressure and chemical action combined, and is produced subsequently to the deposition of the rock.

CHAPTER X

CRYSTALLOGRAPHIC SYMMETRY

THE symmetry of the different crystal groups can be conveniently represented by the method employed by Gadolin * in 1867. This method projects the crystal as a sphere whose center is the point of intersection of the crystallographic axes. The *positions* of the planes of symmetry are shown by the *circle* and *curved lines* drawn within the circle. If this circle or these lines are drawn as *full lines*, each one indicates a plane of symmetry; if they are shown as *dotted or broken lines*, the plane of symmetry is wanting. See Figs. 581–612.

The crystallographic axes are indicated by straight lines marked at the extremities by *arrow feathers.* If these axes are drawn as continuous black lines, each axis is an axis of symmetry; if the axial lines are formed by *dots* or *dashes*, making a broken line, then each axis is not an axis of symmetry. See Figs. 581–

* Abhandlung über die Herleitung aller Krystallographischer Systeme mit ihren Unterabtheilungen aus einem einzigen Prinzipe von Axel Gadolin (1867), Leipzig, 1896.

612. An axis of binary symmetry is indicated by a *black spindle-shaped figure* (Fig. 587); one of trigonal symmetry by a *black triangle* (Fig. 592); one of tetragonal symmetry by a *black quadrilateral* (Fig. 589), and one of hexagonal symmetry by a *black hexagon* (Fig. 593). The center of symmetry is designated in this book by a small circle inclosing the centers of the figures and the central symbols of the axes of symmetry, if there are any.

A. TRICLINIC SYSTEM

This system has a *center of symmetry*, but it has *neither plane nor axis of symmetry.* See pages 19, 20; Fig. 581.

B. MONOCLINIC SYSTEM

I. The **Holohedral Forms** have a *plane of symmetry, an axis of binary symmetry*, and *a center of symmetry.* See pages 40, 41; Fig. 582.

II. The **Clinohedral** or **Hemihedral Forms** have *a plane of symmetry* but they have *neither axis nor center of symmetry.* See pages 45, 46; Fig. 583.

C. ORTHORHOMBIC SYSTEM

I. The **Holohedral Forms** have *three planes of symmetry, three axes of binary symmetry*, and *a center of symmetry.* See pages 51, 52; Fig. 584.

II. The **Hemihedral Forms** have *three axes of binary*

symmetry, but they have *neither plane nor center of symmetry*. See page 55; Fig. 585.

III. The **Hemimorphic Forms** have *two planes of symmetry* and *one axis of binary symmetry*, but they have *no center of symmetry*. See page 56; Fig. 586.

D. TETRAGONAL SYSTEM

I. The **Holohedral Forms** have *five planes of symmetry, one axis of tetragonal symmetry, four axes of binary symmetry*, and *a center of symmetry*. See page 64; Fig. 587.

II. The three divisions of the **Hemihedral Forms** have different symmetries, as follows:

1. The **Sphenoidal Group** has *two planes of symmetry* and *three axes of binary symmetry*, but it has *no center of symmetry*. See pages 66, 67; Fig. 588.

2. The **Pyramidal Group** has *one plane of symmetry, one axis of tetragonal symmetry*, and *a center of symmetry*. See pages 68, 69; Fig. 589.

3. The **Trapezohedral Group** has *one axis of tetragonal symmetry* and *four axes of binary symmetry*, but it has *neither plane nor center of symmetry*. See page 69; Fig. 590.

E. HEXAGONAL SYSTEM

I. The **Holohedral Forms** have *seven planes of symmetry, one axis of hexagonal symmetry, six axes of binary symmetry*, and *a center of symmetry*. See pages 84, 85; Fig. 591.

II. The four divisions of the **Hemihedral Forms** differ in symmetry, as follows:

1. The **Rhombohedral Group** has *three planes of symmetry, one axis of trigonal symmetry, three axes of binary symmetry,* and *a center of symmetry.* See pages 90, 91; Fig. 592.

2. The **Pyramidal Group** has *one plane of symmetry, one axis of hexagonal symmetry,* and *a center of symmetry.* See page 93; Fig. 593.

3. The **Trapezohedral Group** has *one axis of hexagonal symmetry* and *six axes of binary symmetry,* but it *has neither plane nor center of symmetry.* See page 94; Fig. 594.

4. The **Trigonal Group** has *four planes of symmetry, one axis of trigonal symmetry, three axes of binary symmetry,* and *a center of symmetry.* See page 96; Fig. 595.

III. The three divisions of the **Tetartohedral Forms** possess symmetry as follows:

1. The **Rhombohedral Group** has *an axis of trigonal symmetry* and *a center of symmetry,* but it has *no plane of symmetry.* See page 98; Fig. 596.

2. The **Trapezohedral Group** has *an axis of trigonal symmetry* and *three axes of binary symmetry,* but it has *neither plane nor center of symmetry.* See pages 98–100; Fig. 597.

3. The **Trigonal Group** has *one plane of symmetry*

and *one axis of trigonal symmetry*, but it has *no center of symmetry*. See pages 101, 102; Fig. 598.

IV. The four divisions of the **Hemimorphic Forms** show diverse symmetries, as follows:

1. The **Iodyrite Type** has *six planes of symmetry* and *an axis of hexagonal symmetry*, but it has *no center of symmetry*. See pages 102, 103; Fig. 599.

2. The **Nephelite Type** has *an axis of hexagonal symmetry*, but it has *neither plane nor center of symmetry*. See page 103; Fig. 600.

3. The **Tourmaline Type** has *three planes of symmetry and an axis of trigonal symmetry*, but it has *no center of symmetry*. See page 103; Fig. 601.

4. The **Sodium Periodate Type** has *an axis of trigonal symmetry*, but it has *neither plane nor center of symmetry*. See pages 103, 104; Fig. 602.

F. ISOMETRIC SYSTEM

I. The **Holohedral Forms** have *nine planes of symmetry, three axes of tetragonal symmetry, four axes of trigonal symmetry, six axes of binary symmetry*, and *a center of symmetry*. See pages 125–131; Fig. 603.

II. The three divisions of the **Hemihedral Forms** show symmetry as follows:

1. The **Oblique Hemihedral Forms** have *six planes of symmetry, four axes of trigonal symmetry*, and *three axes of binary symmetry*, but they have *no center of symmetry*. See pages 131–135; Fig. 604.

2. The **Parallel Hemihedral Forms** have *three planes of symmetry, four axes of trigonal symmetry, three axes of binary symmetry*, and *a center of symmetry*. See pages 135–138; Fig. 605.

3. The **Gyroidal Hemihedral Forms** have *three axes of tetragonal symmetry, four axes of trigonal symmetry*, and *six axes of binary symmetry*, but they have *neither plane nor center of symmetry*. See pages 138, 139; Fig. 606.

4. The **Tetartohedral Forms** have *four axes of trigonal symmetry*, and *three axes of binary symmetry*, but they have *neither plane nor center of symmetry*. See pages 140, 141; Fig. 607.

CHAPTER XI

THE THIRTY-TWO CLASSES OF CRYSTALS

As a result of the labors of Frankenheim, Hessel, Bravais, Gadolin, and others it is possible within the six crystallographic systems to arrange thirty-two classes of crystals which shall be distinguished by a difference in their symmetry. This method is employed largely in the more recent works relating to Crystallography and Mineralogy, particularly in Europe. Perhaps no one has done more in recent times to popularize this method of studying Crystallography than has Groth, whose work will be chiefly followed below. Edward S. Dana has made extensive use of these classes in his valuable *Text-Book of Mineralogy* (1898), as have also Penfield, Kraus, and Moses and Parsons in their works. The chief class or group names used in this book and by Groth are denoted by **heavy-faced type.**

A. TRICLINIC SYSTEM

(1). I. **Asymmetric Class,** Unsymmetrical Class, Asymmetric Group, **Hemihedral Class,** Hemipinacoidal Class, Pedial Class.

This crystal form is found only amongst artificial crystals, and was therefore not given in the preceding text. The form consists of one face only, and it has *no plane, axis or center of symmetry*. (Fig. 608.) Each form that consists of a single face is called a *Pedion* (Greek *Pedion*, a "plain, flat or field").

The forms of the Asymmetric Class are given below. In all these classes seven forms are placed.

1. First Pedion:

a. Positive, 100.

b. Negative, $\bar{1}00$.

2. Second Pedion:

a. Positive, 010.

b. Negative, $0\bar{1}0$.

3. Third Pedion:

a. Positive, 001.

b. Negative, $00\bar{1}$.

4. Primary Pedion, $0kl$.

5. Secondary Pedion, $h0l$.

6. Tertiary Pedion, $hk0$.

7. Quaternary Pedion, hkl.

(2.) II. **Pinacoidal Class, Holohedral Class,** Centrosymmetric Class, Normal Group. See pages 19, 20 and 162; Fig. 581.

The forms of this class are as follows:

1. First Pinacoid, 100.

2. Second Pinacoid, 010.

3. Third Pinacoid, 001.
4. Primary Pinacoid, $0kl$.
5. Secondary Pinacoid, $h0l$.
6. Tertiary Pinacoid, $hk0$.
7. Quaternary Pinacoid, hkl.

B. MONOCLINIC SYSTEM

(3). I. **Sphenoidal Class, Hemimorphic Class.**

The forms of this class have *one axis of binary symmetry*, but they have *neither plane nor center of symmetry*. Fig. 609.

As crystals of this class occur only in artificial products like lithium sulphate, sugar, tartaric acid, etc., they have not been mentioned on the preceding pages. The forms of this class are as follows:

1. First Pinacoid, 100.
2. Second Pedion:
    a. Right-handed, 010.
    b. Left-handed, $0\bar{1}0$.
3. Third Pinacoid, 001.
4. Primary Sphenoid, $0kl$.
5. Secondary Pinacoid, $h0l$.
6. Tertiary Sphenoid, $hk0$.
7. Quaternary Sphenoid, hkl.

(4). II. **Domatic Class, Clinohedral Group, Hemihedral Class.** See pages 48, 162; Fig. 583.

The forms are as follows:

1. First Pedion:

a. Positive [Front], 100.

b. Negative [Back], $\bar{1}00$.

2. Second Pinacoid, 010.

3. Third Pedion:

a. Positive [Over], 100.

b. Negative [Under], $\bar{1}00$.

4. Primary Dome, $0kl$.

5. Secondary Pedion, $h0l$.

6. Tertiary Dome, $hk0$.

7. Quaternary Dome, hkl.

(**5**). III. **Prismatic Class, Holohedral Class,** Normal Group. See pages 45, 162; Fig. 582.

Forms:

1. First Pinacoid, 100.

2. Second Pinacoid, 010.

3. Third Pinacoid, 001.

4. Primary Prism, $0kl$.

5. Secondary Pinacoid, $h0l$.

6. Tertiary Prism, $hk0$.

7. Quaternary Prism, hkl.

C. ORTHORHOMBIC SYSTEM

(**6**). I. **Bisphenoidal Class, Hemihedral Class,** Sphenoidal Group, Tetrahedral Hemihedral Class. See pages 51, 52, 162, 163; Fig. 585.

Forms:

1. First Pinacoid, 100.
2. Second Pinacoid, 010.
3. Third Pinacoid, 001.
4. Primary Prism, $0kl$.
5. Secondary Prism, $h0l$.
6. Tertiary Prism, $hk0$.
7. Sphenoid, hkl.

(7). II. **Pyramidal Class, Hemimorphic Class.** See pages 56, 163; Fig. 586.

Forms:

1. First Pinacoid, 100.
2. Second Pinacoid, 010.
3. Third Pedion:
   a. Over, 001.
   b. Under, $00\bar{1}$.
4. Primary Dome, $0kl$.
5. Secondary Dome, $h0l$.
6. Tertiary Prism, $hk0$.
7. Quaternary Pyramid, hkl.

(8). III. **Bipyramidal Class, Holohedral Class,** Normal Group. See pages 51, 52, 162; Fig. 584.

Forms:

1. First Pinacoid, 100.
2. Second Pinacoid, 010.
3. Third Pinacoid, 001.
4. Primary Prism, $0kl$.

5. Secondary Prism, $h0l$.
6. Tertiary Prism, $hk0$.
7. Pyramid, hkl.

D. TETRAGONAL SYSTEM

(9). I. **Bisphenoidal Class,** Sphenoidal Tetartohedral Class, Tetartohedral Group, **Tetartohedral Class,** Tetrahedral Tetartohedral Class.

The forms of this class have *one axis of binary symmetry,* but they have *neither plane nor center of symmetry.* See Fig. 610.

As there is no known example of this class, the forms have not been mentioned in the earlier pages of this book.

Forms:

1. Basal Pinacoid, 001.
2. Primary Prism, 110.
3. Secondary Prism, 100.
4. Tertiary Prism, $hk0$.
5. Primary Sphenoid, hhl.
6. Secondary Sphenoid, $h0l$.
7. Tertiary Sphenoid, hkl.

(10). II. **Pyramidal Class, Hemimorphic Hemihedral Class,** Hemimorphic Tetartohedral Class, **Pyramidal Hemimorphic Class,** Hemimorphic Group of the Pyramidal Hemihedral Class, Class of Tetragonal Pyramid of the Third Order, Tetartomorphic Class.

These forms have *one axis of tetragonal symmetry*, but they have *neither plane nor center of symmetry*. See Fig. 611.

Inasmuch as Wulfenite is the only mineral assigned to this class, and there is reason to doubt whether it really belongs in this group, the Pyramidal Class was not touched upon in the earlier pages of this book.

Forms:

1. Basal Pinacoid:
    - a. Over [Positive], 001.
    - b. Under [Negative], $00\bar{1}$.
2. Primary Prism, 110.
3. Secondary Prism, 100.
4. Tertiary Prism, *hk*0.
5. Primary Pyramid, *hhl*.
6. Secondary Pyramid, *h*0*l*.
7. Tertiary Pyramid, *hkl*.

(**11**). III. **Scalenohedral Class,** Sphenoidal Hemihedral Class, Tetrahedral Hemihedral Class, **Sphenoidal Group**.

According to the majority of crystallographers this class, in the preceding text, is said to have *two planes of symmetry* and *three axes of binary symmetry*, but to have *no center of symmetry*. Groth, and after him Moses and Parsons, give the symmetry of this class as follows: *Two planes of symmetry, one axis of tetragonal symmetry*, and *two axes of binary symmetry*, but *no center of symmetry*.

The axis of tetragonal symmetry is coincident with the vertical axis of each form. See pages 66, 67, 163; Fig. 588.

Forms:

1. Basal Pinacoid, 001.
2. Primary Prism, 110.
3. Secondary Prism, 100.
4. Ditetragonal Prism, $hk0$.
5. Primary Sphenoid, hhl.
6. Secondary Pyramid, $h0l$.
7. Scalenohedron, hkl.

(12). IV. **Trapezohedral Class, Trapezohedral Group,** Trapezohedral Hemihedral Class. See pages 68, 163; Fig. 590.

Forms:

1. Basal Pinacoid, 001.
2. Primary Prism, 110.
3. Secondary Prism, 100.
4. Ditetragonal Prism, $hk0$.
5. Primary Pyramid, hhl.
6. Secondary Pyramid, $h0l$.
7. Trapezohedron, hkl.

(13). V. **Bipyramidal Class, Pyramidal Group,** Pyramidal Hemihedral Class. See pages 68, 69, 163; Fig. 589.

Forms:

1. Basal Pinacoid, 001.

2. Primary Tetragonal Prism, 110.
3. Secondary Tetragonal Prism, 100.
4. Tertiary Tetragonal Prism, *hk*0.
5. Primary Tetragonal Pyramid, *hhl*.
6. Secondary Tetragonal Pyramid, *h*0*l*.
7. Tertiary Tetragonal Pyramid, *hkl*.

(**14**). VI. **Ditetragonal Pyramidal Class,** Hemimorphic Holohedral Class, Hemimorphic Group, Pyramidal Hemihedral Class, Class of the Ditetragonal Pyramid, Hemimorphic Hemihedral Class.

The forms of this class possess *four planes of symmetry* and *one tetragonal axis of symmetry*, but *no center of symmetry*. As no mineral is known to occur in the Ditetragonal Pyramidal Class, this group was omitted from the earlier part of this work. See Fig. 612.

Forms:

1. Basal Pinacoid:
   - **a.** Over [Positive], 001.
   - **b.** Under [Negative], $00\bar{1}$.
2. Primary Tetragonal Prism, 110.
3. Secondary Tetragonal Prism, 100.
4. Ditetragonal Prism, *hk*0.
5. Primary Tetragonal Pyramid, *hhl*.
6. Secondary Tetragonal Pyramid, *h*0*l*.
7. Ditetragonal Pyramid, *hkl*.

(**15**). VII. **Ditetragonal-Bipyramidal Class, Holohedral Class,** Normal Group, Class of the Ditetragonal Bipyramid. See pages 64, 163; Fig. 587.

Forms:

1. **Basal Pinacoid, 001.**
2. **Primary Tetragonal Prism, 110.**
3. **Secondary Tetragonal Prism, 100.**
4. **Ditetragonal Prism, *hk*0.**
5. **Primary Tetragonal Pyramid, *hhl*.**
6. **Secondary Tetragonal Pyramid, *h*0*l*.**
7. **Ditetragonal Pyramid, *hkl*.**

E. HEXAGONAL SYSTEM

A. Trigonal or Rhombohedral Division

(16). I. **Trigonal Pyramidal Class, Ogdohedral Class,** Ogdomorphous Class, Hemimorphic Tetartohedral Class, Hemimorphic Trigonal Tetartohedral Class, **Sodium Periodate Type,** Class of the Hemimorphic Trigonal Pyramid of the Third Order. See pages 103, 104, 165; Fig. 602.

Forms:

1. Basal Pinacoid:
   - a. Over [Positive], 0001.
   - b. Under [Negative], $000\bar{1}$.
2. Primary Trigonal Prism:
   - a. Positive, $10\bar{1}0$.
   - b. Negative, $\bar{1}010$.
3. Secondary Trigonal Prism:
   - a. Right-handed, $11\bar{2}0$.
   - b. Left-handed, $2\bar{1}\bar{1}0$.

4. Tertiary Trigonal Prism, $hk\bar{i}0$.
5. Primary Trigonal Pyramid, $h0\bar{h}l$.
6. Secondary Trigonal Pyramid, $h.h.\overline{2h}.l$.
7. Tertiary Trigonal Pyramid, $hk\bar{i}l$.

(**17**). II. **Rhombohedral Class,** Rhombohedral Tetartohedral Class, Trigonal Tetartohedral Class, Class of the Rhombohedron of the Third Order, Tri-rhombohedral Group, Trigonal Rhombohedral Class. See pages 98, 164; Fig. 596.

Forms:

1. Basal Pinacoid, 0001.
2. Primary Hexagonal Prism, $10\bar{1}0$.
3. Secondary Hexagonal Prism, $11\bar{2}0$.
4. Tertiary Hexagonal Prism, $hk\bar{i}0$.
5. Primary Rhombohedron, $h0\bar{h}l$.
6. Secondary Rhombohedron, $h.h.\overline{2h}.l$.
7. Tertiary Rhombohedron, $hk\bar{i}l$.

(**18**). III. **Trigonal Trapezohedral Class,** Trapezohedral Tetartohedral Class, Class of the Trigonal Trapezohedron, **Trapezohedral Group**. See pages 98–100, 164; Fig. 597.

Forms:

1. Basal Pinacoid, 0001.
2. Primary Hexagonal Prism, $10\bar{1}0$.
3. Secondary Trigonal Prism, $11\bar{2}0$.
4. Ditrigonal Prism, $hk\bar{i}0$.
5. Primary Rhombohedron, $h0\bar{h}l$.

6. Secondary Trigonal Pyramid, $h.h.2\bar{h}.l$.
7. Trigonal Trapezohedron, $hk\bar{i}l$.

(19). IV. **Trigonal Bipyramidal Class,** Trigonotype Tetartohedral Class, Sphenoidal Tetartohedral Class, **Trigonal Tetartohedral Class, Trigonal Group,** Class of the Trigonal Bipyramid of the Third Order, Class of the Trigonal Pyramid of the Third Order.

There is no example of this class known. See pages 101, 164; Fig. 598.

Forms:

1. Basal Pinacoid, 0001.
2. Primary Trigonal Prism, $10\bar{1}0$.
3. Secondary Trigonal Prism, $11\bar{2}0$.
4. Tertiary Trigonal Prism, $hk\bar{i}0$.
5. Primary Trigonal Pyramid, $h0\bar{h}l$.
6. Secondary Trigonal Pyramid, $h.h.\overline{2h}.l$.
7. Tertiary Trigonal Pyramid, $hk\bar{i}l$.

(20). V. **Ditrigonal Pyramidal Class,** Hemimorphic Hemihedral Class, Ditrigonal Pyramidal Tetartohedral Class, Rhombohedral Hemihedral Class, Hemimorphic Trigonal Hemihedral Class, Class of the Ditrigonal Pyramid, Hemimorphic Class, Rhombohedral Hemimorphic Class, Hemimorphic Rhombohedral Hemihedral Class, Second Hemimorphic Tetartohedral Class, **Tourmaline Type.** See pages 103, 165; Fig. 601.

Forms:

1. Basal Pinacoid:

a. Over, 0001.

b. Under, $000\bar{1}$.

2. Primary Trigonal Prism:

a. Positive, $10\bar{1}0$.

b. Negative, $\bar{1}010$.

3. Secondary Hexagonal Prism, $11\bar{2}0$.

4. Ditrigonal Prism, $hk\bar{i}0$.

5. Primary Trigonal Pyramid, $h0\bar{h}l$.

6. Secondary Hexagonal Pyramid, $h.h.\overline{2h}.l$.

7. Ditrigonal Pyramid, $hk\bar{i}l$.

(21). VI. **Ditrigonal Scalenohedral Class,** Rhombohedral Hemihedral Class, Scalenohedral Rhombohedral Class, Class of the Ditrigonal Scalenohedron, Scalenohedral Class, Normal Rhombohedral Group, **Rhombohedral Group.** See pages 90, 91, 164; Fig. 592.

Forms:

1. Basal Pinacoid, 0001.

2. Primary Hexagonal Prism, $10\bar{1}0$.

3. Secondary Hexagonal Prism, $11\bar{2}0$.

4. Dihexagonal Prism, $hk\bar{i}0$.

5. Primary Rhombohedron, $h0\bar{h}l$.

6. Secondary Hexagonal Pyramid, $h.h.\overline{2h}.l$.

7. Hexagonal Scalenohedron, $hk\bar{i}l$.

(22). VII. **Ditrigonal Bipyramidal Class,** Trigono-

type Hemihedral Class, Sphenoidal-Hemihedral Class, Trigonal Hemihedral Class, Class of the Ditrigonal Bipyramid, Class of the Ditrigonal Pyramid, **Trigonal Group**. No examples are known of this class. See pages 96, 164; Fig. 595.

Forms:

1. Basal Pinacoid, 0001.
2. Primary Trigonal Prism, $10\bar{1}0$.
3. Secondary Hexagonal Prism, $11\bar{2}0$.
4. Ditrigonal Prism, $hk\bar{i}0$.
5. Primary Trigonal Pyramid, $h0\bar{h}l$.
6. Secondary Hexagonal Pyramid, $h.h.\overline{2h}.l$.
7. Ditrigonal Pyramid, $hk\bar{i}l$.

B. Hexagonal Division

(**23**). VIII. **Hexagonal Pyramidal Class,** Hemimorphic Hemihedral Class, First Hemimorphic Tetartohedral Class, Tetartomorphic Class, Hemimorphic Pyramidal Hemihedral Class, Pyramidal Hemimorphic Class, Hexagonal Pyramidal Tetartohedral Class, Class of the Third Order Hexagonal Pyramid, **Nephelite Type.** See pages 103, 165; Fig. 600.

Forms:

1. Basal Pinacoid:
   a. Over [Positive], 0001.
   b. Under [Negative], $000\bar{1}$.
2. Primary Hexagonal Prism, $10\bar{1}0$.

3. Secondary Hexagonal Prism, $11\bar{2}0$.
4. Tertiary Hexagonal Prism, $hk\bar{i}0$.
5. Primary Hexagonal Pyramid, $h0\bar{h}l$.
6. Secondary Hexagonal Pyramid, $h.h.\overline{2h}.l$.
7. Tertiary Hexagonal Pyramid, $hk\bar{i}l$.

(24). IX. **Hexagonal Trapezohedral Class,** Trapezohedral Hemihedral Class, Trapezohedral Class, **Trapezohedral Group,** Class of the Hexagonal Trapezohedron.

Only some artificial chemical compounds occur in the forms of this class. See pages 94, 164; Fig. 594.

Forms:

1. Basal Pinacoid, 0001.
2. Primary Hexagonal Prism, $10\bar{1}0$.
3. Secondary Hexagonal Prism, $11\bar{2}0$.
4. Dihexagonal Prism, $hk\bar{i}0$.
5. Primary Hexagonal Pyramid, $h0\bar{h}l$.
6. Secondary Hexagonal Pyramid, $h.h.\overline{2h}.l$.
7. Hexagonal Trapezohedron, $hk\bar{i}l$.

(25). X. **Hexagonal Bipyramidal Class,** Pyramidal Hemihedral Class, Bipyramidal Class, **Pyramidal Group,** Tripyramidal Group, Class of the Third Order Hexagonal Bipyramid, Class of the Third Order Hexagonal Pyramid. See pages 93, 164; Fig. 593.

Forms:

1. Basal Pinacoid, 0001.
2. Primary Hexagonal Prism, $10\bar{1}0$.

3. Secondary Hexagonal Prism, $11\bar{2}0$.
4. Tertiary Hexagonal Prism, $hk\bar{i}0$.
5. Primary Hexagonal Pyramid, $h0\bar{h}l$.
6. Secondary Hexagonal Pyramid, $h.h.\overline{2h}.l$.
7. Tertiary Hexagonal Pyramid, $hk\bar{i}l$.

(26.) XI. **Dihexagonal Pyramidal Class,** Hexagonal Hemimorphic Class, Hemimorphic Holohedral Class, Hemimorphic Hemihedral Class, **Hemimorphic Group,** Class of the Dihexagonal Pyramid, Class of Hemimorphic Dihexagonal Pyramid, **Iodyrite Type**. See pages 102, 165; Fig. 599.

Forms:

1. Basal Pinacoid:
   a. Over [Positive], 0001.
   b. Under [Negative], $000\bar{1}$.
2. Primary Hexagonal Prism, $10\bar{1}0$.
3. Secondary Hexagonal Prism, $11\bar{2}0$.
4. Dihexagonal Prism, $hk\bar{i}0$.
5. Primary Hexagonal Pyramid, $h0\bar{h}l$.
6. Secondary Hexagonal Pyramid, $h.h.\overline{2h}.l$.
7. Dihexagonal Pyramid, $hk\bar{i}l$.

(27). XII. **Dihexagonal Bipyramidal Class,** Holohedral Hexagonal Class, Holohedral Class, **Holohedral Group,** Normal Group, Class of Dihexagonal Pyramid, Class of the Dihexagonal Bipyramid. See pages 84, 85, 163; Fig. 591.

Forms:

1. Basal Pinacoid, 0001.
2. Primary Hexagonal Prism, $10\bar{1}0$.
3. Secondary Hexagonal Prism, $11\bar{2}0$.
4. Dihexagonal Prism, $hk\bar{i}0$.
5. Primary Hexagonal Pyramid, $h0\bar{h}l$.
6. Secondary Hexagonal Pyramid, $h.h.\overline{2h}.l$.
7. Dihexagonal Pyramid, $hk\bar{i}l$.

F. ISOMETRIC SYSTEM

(28). I. **Tetrahedral Pentagonal Dodecahedral Class,** Tetartohedral Class, **Tetartohedral Group,** Class of the Tetartoid. See pages 140, 166; Fig. 607.

Forms:

1. Hexahedron or Cube, 100.
2. Dodecahedron, 110.
3. Tetrahedron:
   a. Positive, 111.
   b. Negative, $1\bar{1}1$.
4. Pentagonal Dodecahedron:
   a. Right-handed, $hk0$.
   b. Left-handed, $kh0$.
5. Trigonal Triakis Tetrahedron:
   a. Positive, hll.
   b. Negative, $h\bar{l}l$.
6. Tetragonal Triakis Tetrahedron:
   a. Positive, hhl.
   b. Negative, $h\bar{h}l$.

7. Tetrahedral Pentagonal Dodecahedron:
   - a. Positive Right-handed, hkl.
   - b. Positive Left-handed, lkh.
   - c. Negative Right-handed, $l\bar{k}h$.
   - d. Negative Left-handed, $h\bar{k}l$.

(29). II. **Pentagonal Icositetrahedral Class,** Plagihedral Hemihedral Class, **Plagihedral Group,** Gyroidal Hemihedral Class, **Gyroidal Group,** Class of the Gyroid. See pages 138, 166; Fig. 606.

Forms:

1. Hexahedron or Cube, 100.
2. Dodecahedron, 110.
3. Octahedron, 111.
4. Tetrakis Hexahedron, $hk0$.
5. Tetragonal Triakis Octahedron, hll.
6. Trigonal Triakis Octahedron, hhl.
7. Pentagonal Icositetrahedron:
   - a. Right-handed, hkl.
   - b. Left-handed, lkh.

(30). III. **Dyakis Dodecahedral Class, Parallel Hemihedral Class,** Pentagonal Hemihedral Class, **Pyritohedral Group,** Pyritohedral Hemihedral Group, Class of the Diploid. See pages 135, 166; Fig. 605.

Forms:

1. Hexahedron or Cube, 100.
2. Dodecahedron, 110.
3. Octahedron, 111.

4. Pentagonal Dodecahedron:
    a. Right-handed, $hk0$.
    b. Left-handed, $kh0$.
5. Tetragonal Triakis Octahedron, hll.
6. Trigonal Triakis Octahedron, hhl.
7. Dyakis Dodecahedron:
    a. Right-handed, hkl.
    b. Left-handed, khl.

(**31**). IV. **Hexakis Tetrahedral Class,** Inclined Hemihedral Class, Inclined-Faced Hemihedral Class, Tetrahedral Group, Tetrahedral Hemihedral Class, Class of the Hextetrahedron, Hextetrahedral Class, **Oblique Hemihedral Class**. See pages 131, 165; Fig. 604.

Forms:

1. Hexahedron or Cube, 100.
2. Dodecahedron, 110.
3. Tetrahedron:
    a. Positive, 111.
    b. Negative, $1\bar{1}1$.
4. Tetrakis Hexahedron, $hk0$.
5. Tetragonal Triakis Tetrahedron:
    a. Positive, hhl.
    b. Negative, $h\bar{h}l$.
6. Trigonal Triakis Tetrahedron:
    a. Positive, hll.
    b. Negative, $h\bar{l}l$.

7. Hexakis Tetrahedron:
   a. Positive, *hkl*.
   b. Negative, $h\bar{k}l$.

(32). V. **Hexakis Octahedral Class, Holohedral Class,** Normal Group, Class of the Hexoctahedron, Hexoctahedral Class. See pages 125, 165; Fig. 603.

Forms:

1. Hexahedron or Cube, 100.
2. Dodecahedron, 110.
3. Octahedron, 111.
4. Tetrakis Hexahedron, *hk*0.
5. Tetragonal Triakis Octahedron, *hll*.
6. Trigonal Triakis Octahedron, *hhl*.
7. Hexakis Octahedron, *hkl*.

CHAPTER XII

CRYSTALLOGRAPHIC NOMENCLATURE

THE names in Crystallography are undoubtedly a serious stumbling-block to most students, yet in point of fact crystals are named in a way that is very similar to that in which men are named the world over. Again, the crystallographic names are no more difficult to pronounce than are the names of persons of one nationality to those of different nations and speech. Foreigners make havoc with our proper names, and we have difficulty in learning how to pronounce the names of the emigrants who come to our shores from Russia, Poland, and Bohemia.

The object of applying a name to an individual, variety or species is to distinguish it absolutely from all others. When men live in comparatively small communities and each individual leads a somewhat stationary life, one name has been generally found sufficient; every one is known amongst his fellows as Smith, Brown or Jones, or, it may be, as William, Robert, John or James. When men live in larger communities, or intermingle freely as a result of polit-

ical commotions or the increased facilities for travel, a necessity arises for binomial, or trinomial, or even longer names.

When several individuals of the same name were associated together, some other term than that of the family name was necessary to distinguish each one from his fellows. Accordingly, for the sake of distinction, to a man's given name was added a nickname referring frequently to some personal peculiarity, as, e. g., *Red* Angus, *Black* Douglas or Frederick *Barbarossa*. Later, a secondary name, without any peculiar personal significance, was attached to a man's family name, as, e. g., *William* Shakespeare, *John* Milton or *Ben* Johnson. Later it became necessary or desirable to add one or several middle names, as, e. g., Henry *Wadsworth* Longfellow, Josiah *Dwight* Whitney and Louis *Jean Rudolphe* Agassiz; and thus the modern method of personal nomenclature has been developed.

In the nomenclature of Crystallography the student can observe a marked resemblance to the system followed in the naming of persons. He can notice the single name in the Octahedron; the nickname in the Cube and Gyroid, the family names in the Pinacoids, Pyramids, and Prisms; the double names in the Dyakis Dodecahedron and the Hexakis Octahedron; the trinomial names in the Trigonal Triakis Octahedron, Primary Hexagonal Pyramid, and others.

The resemblance to personal nomenclature can be well seen in the case of the various tribes and families of Prisms, Pyramids, and Pinacoids, and in the Isometric System.

The change of one family name to another, as is common amongst men, is observed in the Domes which are in truth Prisms. Again, the various Trigonal Prisms are descended from the various Hexagonal Prisms, and the Sphenoids from the Pyramids, as are also the Trapezohedrons, Rhombohedrons, and Scalenohedrons. In the Isometric Tribe can be found the families of the Tetrakis Hexahedrons and Octahedrons, with their various descendants.

It is thought that the tabulation given below, which associates the related forms and enumerates many of their names, will furnish the observant student with a new method of retaining in his memory the true relationship of the various forms.

W. The Families of the Prism Tribe

A. THE FAMILY OF TRICLINIC PRISMS

I. **Triclinic Hemi Vertical Prism,*** *alias* Triclinic Hemi Vertical Dome, Hemi Prism, **Vertical Prism,** Triclinohedral Prism, Klinorhombohedral Prism, etc.

* In these lists the names used chiefly in this book are printed in **heavy-faced** type.

II. **Triclinic Hemi Brachy Prism,** *alias* **Triclinic Hemi Brachy Dome,** Hemi Brachy Dome, **Brachy Dome,** Horizontal Prism, Second Horizontal Prism, Hemi Dome, etc.

III. Triclinic Hemi Macro Prism, *alias* **Triclinic Hemi Macro Dome,** Hemi Macro Dome, **Macro Dome,** Horizontal Prism, First Horizontal Prism, Hemi Dome, etc.

B. THE FAMILY OF MONOCLINIC PRISMS

I. **Monoclinic Vertical Prism,** *alias* Monoclinic Vertical Dome, **Vertical Prism,** Oblique Rhombic Prism, Rhombic Prism, etc.

II. Monoclinic Clino Prism, *alias* **Monoclinic Clino Dome, Clino Dome,** Clino Diagonal Prism, Horizontal Prism, Horizontal Prism of a Rhombohedral Section.

III. Monoclinic Hemi Ortho Prism, *alias* **Monoclinic Hemi Ortho Dome, Hemi Ortho Dome.**

C. THE FAMILY OF ORTHORHOMBIC PRISMS

I. **Orthorhombic Vertical Prism,** *alias* Orthorhombic Vertical Dome, **Vertical Prism,** Rhombic Prism, Vertical Rhombic Prism, Oblique Angled Quadralateral Prism, Vertical Quadralateral Prism, etc.

II. Orthorhombic Brachy Prism, *alias* **Orthorhombic Brachy Dome, Brachy Dome,** Brachy Diagonal Dome, Brachy Diagonal Prism, Horizontal Prism, Second Horizontal Prism, etc.

III. Orthorhombic Macro Prism, *alias* **Orthorhombic Macro Dome,** Macro Dome, Macro Diagonal Dome, Macro Diagonal Prism, Horizontal Prism, First Horizontal Prism, etc.

D. THE FAMILY OF TETRAGONAL PRISMS

I. **Primary Prism,** *alias* **Direct Prism,** Unit Prism, Prism of the First Order, Quadratic Prism, Tetragonal Prism of the First Order, **Primary Tetragonal Prism,** Direct Tetragonal Prism, etc.

II. **Secondary Prism,** *alias* **Inverse Prism,** Diametral Prism, Prism of the Second Order, **Secondary Tetragonal Prism,** Inverse Tetragonal Prism, Quadratic Prism, Tetragonal Prism of the Second Order, etc.

III. **Di Tetragonal Prism,** *alias* **Di Octahedral Prism,** Octagonal Prism, etc.

1. Hemi Di Tetragonal Prism, *alias* **Tertiary Prism,** Prism of the Third Order, Tetragonal Prism of the Third Order.

E. THE FAMILY OF HEXAGONAL PRISMS

I. **Primary Hexagonal Prism,** *alias* Hexagonal Prism of the First Order, Unit Prism, Regular Hexagonal Prism, Hexagonal Prism of the Principal Series, First Hexagonal Prism, etc.

1. Hemi Primary Hexagonal Prism, *alias* **Primary Trigonal Prism,** Trigonal Prism, etc.
    a. *Positive Primary Trigonal Prism.*
    b. *Negative Primary Trigonal Prism.*

II. **Secondary Hexagonal Prism,** *alias* Hexagonal Prism of the Second Order, Diagonal Prism, Regular Hexagonal Prism, Second Hexagonal Prism, Hexagonal Prism of the Second Series.

1. Hemi Secondary Hexagonal Prism, *alias* **Secondary Trigonal Prism,** Prism of the Second Order.
    a. *Positive or Right-Handed Trigonal Prism.*
    b. *Negative or Left-Handed Trigonal Prism.*

III. **Di Hexagonal Prism,** *alias* Do Decagonal Prism, Twelve-sided Prism, etc.

1. Hemi Di Hexagonal Prism, *alias* **Tertiary Hexagonal Prism,** Hexagonal Prism of the Third Order.
    a. *Positive or Right-Handed Hexagonal Prism.*
    b. *Negative or Left-Handed Hexagonal Prism.*
2. Hemi Di Hexagonal Prism, *alias* **Primary Di Trigonal Prism,** Di Trigonal Prism of the First Order.
    a. *Positive Di Trigonal Prism.*
    b. *Negative Di Trigonal Prism.*
3. Hemi Di Hexagonal Prism, *alias* **Secondary**

Di Trigonal Prism, Di Trigonal Prism of the Second Order.

a. *Right-Handed Di Trigonal Prism.*

b. *Left-Handed Di Trigonal Prism.*

4. Tetarto Di Hexagonal Prism, *alias* **Tertiary Trigonal Prism,** Trigonal Prism of the Third Order.

a. *Positive Right-Handed Tertiary Trigonal Prism.*

b. *Positive Left-Handed Tertiary Trigonal Prism.*

c. *Negative Right-Handed Tertiary Trigonal Prism.*

d. *Negative Left-Handed Tertiary Trigonal Prism.*

X. The Families of the Pyramid Tribe

A. THE FAMILY OF TRICLINIC PYRAMIDS

I. **Triclinic Tetarto Pyramid,** *alias* Triclinic Pyramid, Clinorhombic Octahedron, etc. *Nicknames,* Anorthotype, Anorthoid.

B. THE FAMILY OF MONOCLINIC PYRAMIDS

I. **Monoclinic Hemi Pyramid,** *alias* Monoclinic Pyramid, etc. *Nicknames,* Augitoid, Hemiorthotype.

C. THE FAMILY OF ORTHORHOMBIC PYRAMIDS

I. **Orthorhombic Pyramids,** *alias* **Rhombic Pyramid,** Rhombic Pyramidohedron, Rhombic Octahedron, Orthorhombic Octahedron, etc. *Nickname,* Orthotype.

1. Orthorhombic Hemi Pyramid, *alias* Orthorhombic Sphenoid, **Sphenoid,** Rhombic Sphenoid, Rhombic Sphenoidohedron, Rhombic Tetrahedron, Irregular Tetrahedron, etc. *Nickname,* Tartartoid :
    - a. *Positive or Right-handed Orthorhombic Sphenoid.*
    - b. *Negative or Left-handed Orthorhombic Sphenoid.*

D. THE FAMILY OF TETRAGONAL PYRAMIDS

I. **Primary Tetragonal Pyramid,** *alias* **Primary Pyramid,** Direct Tetragonal Pyramid, **Direct Pyramid,** Unit Pyramid, Tetragonal Pyramid of the First Order, Pyramid of the Unit Order, Pyramid of the First Order, Direct Octahedron, Quadratic Octahedron, Quadratic Octahedron of the First Order, Pyramid Octahedron of the First Order, Tetragonal Pyramidohedron of the First Direction, Quadratic Octahedron of the First Series.

1. Hemi Tetragonal Pyramid, *alias* **Tetragonal Sphenoid, Sphenoid,** Quadratic Tetrahedron, Irregular Tetrahedron :

a. *Positive Sphenoid.*

b. *Negative Sphenoid.*

II. **Secondary Tetragonal Pyramid**, *alias* **Secondary Pyramid**, Inverse Tetragonal Pyramid, **Inverse Pyramid**, Diametral Pyramid, Trigonal Pyramid of the Second Order, Pyramid of the Second Order, Inverse Octahedron, Quadratic Octahedron, Quadratic Octahedron of the Second Order, Quadratic Octahedron of the Second Series, Tetragonal Pyramidohedron of the Second Direction, Pyramid of the Diametral Order, Quadratic Pyramid, etc.

III. **Di Tetragonal Pyramid**, *alias* Di Tetragonal Octahedron, Di Octahedron, Di Tetragonal Pyramid of the First Direction. *Nickname*, Zirconoid.

1. Hemi Di Tetragonal Pyramid, *alias* **Tertiary Tetragonal Pyramid, Tertiary Pyramid,** Tetragonal Pyramid of the Third Order, Pyramid of the Third Order, Hemi Di Octahedron:

   a. *Positive Tertiary Pyramid.*

   b. *Negative Tertiary Pyramid.*

2. Hemi Di Tetragonal Pyramid, *alias* **Tetragonal Scalenohedron,** Di Tetragonal Scalenohedron. *Nickname*, Disphene, Diplo Tetrahedron:

   a. *Positive Tetragonal Scalenohedron.*

   b. *Negative Tetragonal Scalenohedron.*

3. Hemi Di Tetragonal Pyramid, *alias* **Tetragonal Trapezohedron,** Quadratic Trapezohedron, Trapezoidal Octahedron, etc.:
   a. *Positive or Right-handed Tetragonal Trapezohedron.*
   b. *Negative or Left-handed Tetragonal Trapezohedron.*

E. THE FAMILY OF HEXAGONAL PYRAMIDS

I. **Primary Hexagonal Pyramid,** *alias* Hexagonal Pyramid of the First Order, Di Hexahedron of the Principal Series, Hexagonal Dodecahedron of the First Order, Right Angled Dodecahedron, Hexagonal Pyramid of the First Division, Hexagonal Pyramidohedron of the First Normal Direction, Quartzoid of the First Order, etc. *Nickname,* Quartzoid.

1. Hemi Primary Hexagonal Pyramid, *alias* **Rhombohedron, Primary Rhombohedron,** Rhombohedron of the First Order, Eight-Angled Hexahedron, Rhombohedron of the Principal Series, Hemi Dodecahedron of the First Order, Rhombohedron of the Vertical Primary Zone.
2. Hemi Primary Hexagonal Pyramid, *alias* **Primary Trigonal Pyramid,** Trigonal Pyramid of the First Order.

II. **Secondary Hexagonal Pyramid,** *alias* Hexagonal

Pyramid of the Second Order, Di Hexahedron of the Second Order, Di Hexahedron of the Principal Series, Hexagonal Dodecahedron of the Second Order, Eight-Angled Dodecahedron, Hexagonal Pyramid of the Second Division, Hexagonal Pyramidohedron of the Second Normal Direction, Quartzoid of the Second Order, etc. *Nickname*, Quartzoid.

1. Hemi Secondary Hexagonal Pyramid, *alias* **Secondary Rhombohedron,** Rhombohedron of the Second Order, etc.
    - **a.** *Positive Secondary Rhombohedron or Positive Rhombohedron of the Second Order.*
    - **b.** *Negative Secondary Rhombohedron or Negative Rhombohedron of the Second Order.*
2. Hemi Secondary Hexagonal Pyramid, *alias* **Secondary Trigonal Pyramid,** Trigonal Pyramid of the Second Order.
    - **a.** *Positive or Right-Handed Trigonal Pyramid.*
    - **b.** *Negative or Left-Handed Trigonal Pyramid.*

III. **Dihexagonal Pyramid,** *alias* Di Dodecahedron. *Nickname*, Berylloid.

1. Hemi Di Hexagonal Pyramid, *alias* Hexagonal Scalenohedron, **Scalenohedron,** Di Hexagonal Scalenohedron, Hemi Dodecahedron, Bi Pyramid. *Nickname*, Calcite Pyramid.
    - **a.** *Positive Scalenohedron.*
    - **b.** *Negative Scalenohedron.*

2. Hemi Di Hexagonal Pyramid, *alias* **Tertiary Hexagonal Pyramid,** Hexagonal Pyramid of the Third Order, Di Hexagonal Hemi Di Dodecahedron, Hemihedral Di Hexahedron.
   - **a.** *Positive or Right-Handed Tertiary Hexagonal Pyramid.*
   - **b.** *Negative or Left-Handed Tertiary Hexagonal Pyramid.*
3. Hemi Di Hexagonal Pyramid, *alias* **Hexagonal Trapezohedron,** Di Hexagonal Trapezohedron, Trapezoid Di Hexahedron. *Nickname,* Diplagihedron.
   - **a.** *Right-Handed Hexagonal Trapezohedron.*
   - **b.** *Left-Handed Hexagonal Trapezohedron.*
4. Tetarto Di Hexagonal Pyramid, *alias* Hemi Hexagonal Scalenohedron, **Tertiary Rhombohedron,** Rhombohedron of the Third Order.
   - **a.** *Positive Right-Handed Tertiary Rhombohedron.*
   - **b.** *Negative Right-Handed Tertiary Rhombohedron.*
   - **c.** *Positive Left-Handed Tertiary Rhombohedron.*
   - **d.** *Negative Left-Handed Tertiary Rhombohedron.*
5. Tetarto Di Hexagonal Pyramid, *alias* **Di Trigonal Pyramid.**

- a. *Positive Di Trigonal Pyramid.*
- b. *Negative Di Trigonal Pyramid.*

6. Tetarto Di Hexagonal Pyramid, *alias* Hemi Hexagonal Scalenohedron, **Trigonal Trapezohedron,** Di Trigonal Trapezohedron, Trigon Trapezohedron. *Nickname,* Plagihedron:
    - a. *Positive Right-handed Trigonal Trapezohedron.*
    - b. *Negative Right-handed Trigonal Trapezohedron.*
    - c. *Positive Left-handed Trigonal Trapezohedron.*
    - d. *Negative Left-handed Trigonal Trapezohedron.*
7. Tetarto Di Hexagonal Pyramid, *alias* Tertiary Trigonal Pyramid, Trigonal Pyramid of the Third Order:
    - a. *Positive Right-handed Tertiary Trigonal Pyramid.*
    - b. *Negative Right-handed Tertiary Trigonal Pyramid.*
    - c. *Positive Left-handed Tertiary Trigonal Pyramid.*
    - d. *Negative Left-handed Tertiary Trigonal Pyramid.*

Y. THE FAMILIES OF THE PINACOID TRIBE

I. **Basal Pinacoid,** *alias* Vertical Pinacoid, Basal Plane, Base, End Plane, etc.

II. **Brachy Pinacoid,** *alias* Brachy Diagonal Pinacoid.

III. **Macro Pinacoid,** *alias* Macro Diagonal Pinacoid.

IV. **Clino Pinacoid.**

V. **Ortho Pinacoid.**

Z. THE FAMILIES OF THE ISOMETRIC TRIBE

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II. **Dodecahedron,** *alias* Rhombic Dodecahedron, Regular Rhombic Dodecahedron, etc. *Nicknames,* Garnet Crystallization, Garnetohedron, Garnetoid, Garnet Dodecahedron.

III. **Tetrakis Hexahedron,** *alias* Tetra Hexahedron, Hexahedral Trigonal Icosi Tetrahedron, Pyramidal Cube, etc. *Nickname,* Fluoroid.

1. Hemi Tetrakis Hexahedron, *alias* **Pentagonal Dodecahedron,** Hexahedral Pentagonal Dodecahedron, Domatic Dodecahedron, etc. *Nicknames,* Pyrite Dodecahedron, Pyritohedron, Pyritoid.

IV. **Octahedron,** *alias* Regular Octahedron, Regular Four-sided Double Pyramid, etc.

1. Hemi Octahedron, *alias* **Tetrahedron,** Regular Tetrahedron, etc.

V. **Trigonal Triakis Octahedron,** *alias* Triakis Octahedron, **Tris Octahedron,** Pyramid Octahedron, Octahedral Trigonal Icosi Tetrahedron, Octahedral Pyramidal Icosi Tetrahedron. *Nickname,* Galenoid.

1. Hemi Trigonal Triakis Octahedron, *alias* **Tetragonal Triakis Tetrahedron,** Tetragonal Tris Tetrahedron, Tris Tetrahedron, Deltoid Dodecahedron, Tetragonal Dodecahedron, Trapezoidal Dodecahedron, Deltohedron, Trapezoid Tetrahedron, etc.

VI. **Tetragonal Triakis Octahedron,** *alias* **Trapezohedron,** Icosi Tetrahedron, Trapezoidal Icosi Tetrahedron, Deltoid Icosi Tetrahedron, etc. *Nicknames,* Leucite Crystallization, Leucitohedron, Leucitoid.

1. Hemi Tetragonal Triakis Octahedron, *alias* **Trigonal Triakis Tetrahedron,** Triakis Tetrahedron, Pyramidal Tetrahedron, Trigonal Dodecahedron, Pyramidal Dodecahedron, Hemi Icosi Tetrahedron, etc. *Nickname,* Cuproid.

VII. **Hexakis Octahedron,** *alias* Hex Octahedron, Octakis Hexahedron, Trigonal Polyhedron, Pyramidal Garnetohedron, etc. *Nickname,* Adamantoid.

1. Hemi Hexakis Octahedron, *alias* **Hexakis Tetrahedron,** Trigonal Icosi Tetrahedron, Tetrahedral Trigonal Icosi Tetrahedron, etc· *Nickname,* Boracitoid.
2. Hemi Hexakis Octahedron, *alias* **Dyakis Dodecahedron,** Hemi Octakis Hexahedron, Tetragonal Icosi Tetrahedron, Trapezoid Icosi Tetrahedron, Trapezoid Di Dodecahedron, etc.

Nicknames, Diploid, Diplo-Pyritohedron, Diplo-Pyritoid, Diplohedron, etc.

3. Hemi Hexakis Octahedron, *alias* Pentagonal Icosi Tetrahedron. *Nickname*, **Gyroid.**

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ERRATA.

Page 7. 7 lines from the top. For "A B C D E F H" read "A B C D."

Page 11. 2 lines from the bottom. For "001" read "$00\bar{1}$."

Page 12. 13 lines from the top. For "$1\bar{1}0 < 111$" read "$011 < 0\bar{1}1$."

Page 21. 8 lines from the top. For "equal" read "unequal."

Page 26. 7 lines from the top. For "35" read "64."

Page 32. 2 lines from the bottom. For "$\breve{P}$" read "$\breve{P}$."

Page 33. 5 lines from the top. For "$'P$" read "$'P$."

Page 35. 6 lines from the bottom. For "$n\bar{b}$" read "$-n\bar{b}$."

Page 35. 2 lines from the bottom. For "$\bar{b}$" read "$-\bar{b}$."

Page 41. 12 lines from the bottom. Strike out "shortest" and for "them" read "their centers."

Page 43. 11 lines from the top. For "65, 70" read "67, 68." 10 lines from the bottom for "82-86" read "82, 84-86."

Page 45. 12 lines from the bottom. For "65 72" read "65-72."

Page 47. 2 lines from the top. For the second $\bar{b}$ read $\overset{1}{\bar{b}}$.

Page 54. 9 lines from the top. For "**Ortho**" read "**Macro.**" 10 lines from the top. For "ortho-" read "macro-." 11 lines from the bottom. For "clino-" read "brachy-" and for "**Clino-**" read "**Brachy-.**" 10 lines from the bottom. For "ortho-" read "macro-." 9 lines from the bottom for "**Ortho-**" read "**Brachy-.**"

Page 57. 13 lines from the top. For "87 135" read "87-135."

Page 60. 2 lines from the bottom. For "147-149" read "151-153."

Page 61. 6 lines from the top. For "147, 150 and" read "151- ."

Page 83. 7 lines from the bottom for "(d)" read "(s)" and for "(b and g)" read "(b and d)."

Page 125. 14 lines from the top. For "Petagonal" read "Pentagonal."

Page 132. 4 and 7 lines from the bottom. Place "upper" before "edge."

Page 133. 10 lines from the bottom. Place "upper" before "edge." 7 lines from the bottom for "845" read "345." 3 lines from the bottom. For "octohedral" read "octahedral."

Page 134. 7 lines from the top. Place "upper" before "edge."

Page 140. 10 lines from the bottom. For "alteration" read "alternation."

Page 144. 14 lines from the top. For "four" read "five." 6 lines from the bottom add: "if the planes are pentagonal; but if they are triangular they belong to the *Hexakis Tetrahedron.*

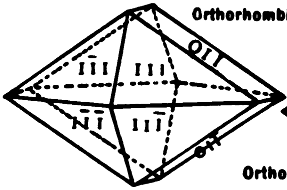
Page 147. 9 lines from the top. For "*lkh*" read "$\bar{l}\bar{k}h$."

Page 151. 3 lines from the top. For "459-460" read "459, 460."

Page 157. 11 lines from the top. For "101" read "$\bar{1}01$."

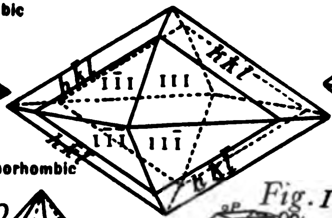
Page 169. Last line. For "48" read "45."

Fig. 113



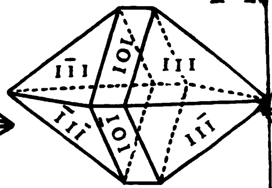
Orthorhombic

Fig. 114



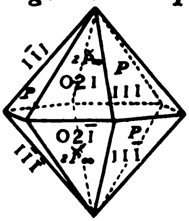
Orthorhombic

Fig. 115



Orthorhombic

Fig. 119



Orthorhombic

Fig. 120

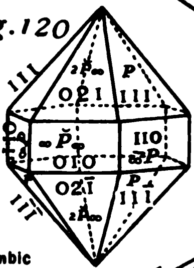
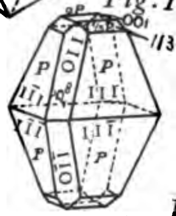
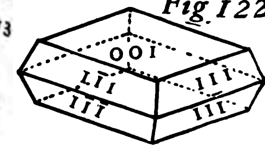


Fig. 121



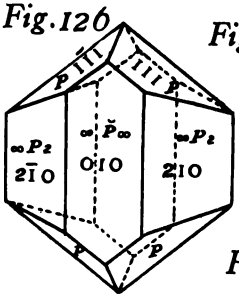
Orthorhombic

Fig. 122



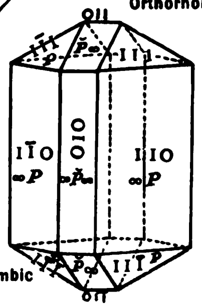
Orthorhombic

Fig. 126



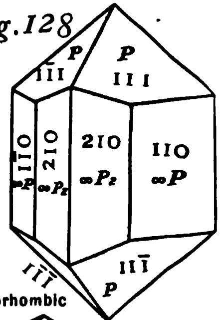
Orthorhombic

Fig. 127



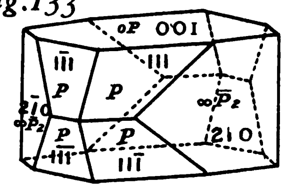
Orthorhombic

Fig. 128



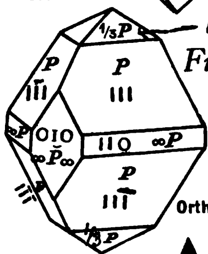
Orthorhombic

Fig. 133



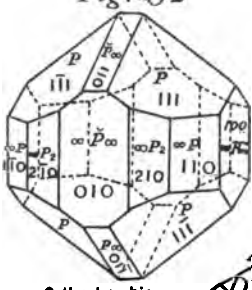
Orthorhombic

Fig. 134



Orthorhombic

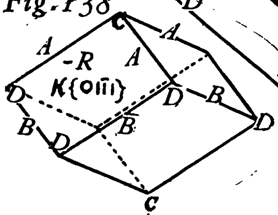
Fig. 132



Orthorhombic

Fig. 139

Fig. 138



Hexagonal Rhombohedrons

Fig. 140
K{hkīl}
mRn

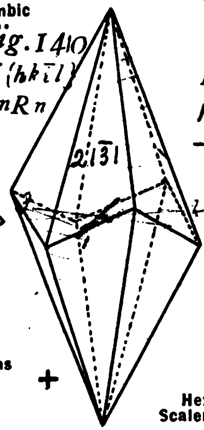
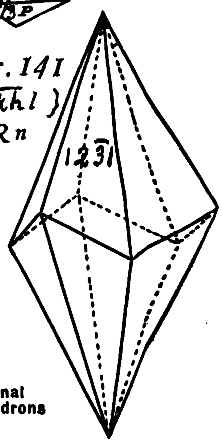


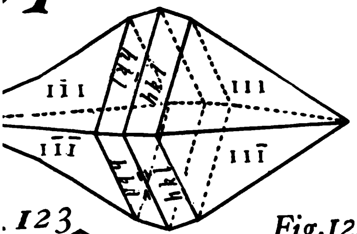
Fig. 141
K{ik̄hl}
-mRn



Hexagonal Scalenohedrons

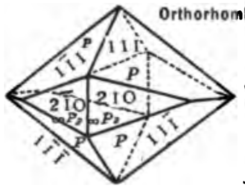
71

Fig 116



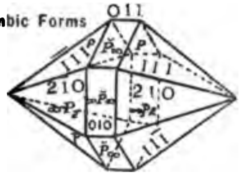
Orthorhombic

Fig.117

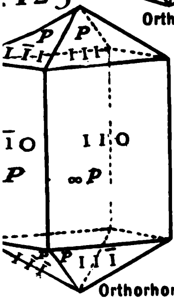


Orthorhombic Forms

Fig 118

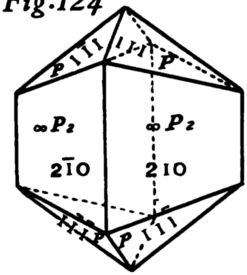


.123



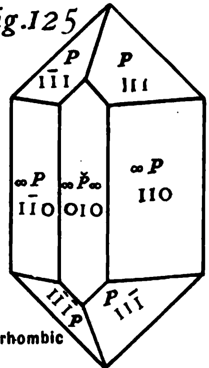
Orthorhombic

Fig.124



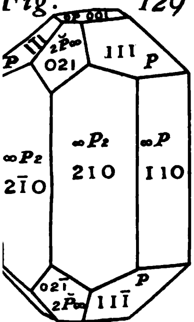
Orthorhombic

Fig.125



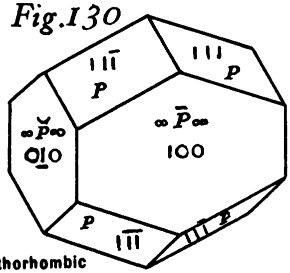
Orthorhombic

Fig. 129



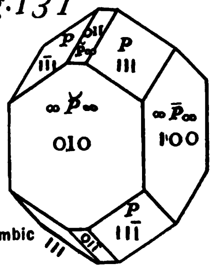
Orthorhombic

Fig.130



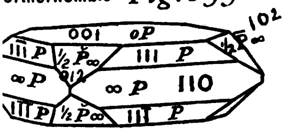
Orthorhombic

Fig.131



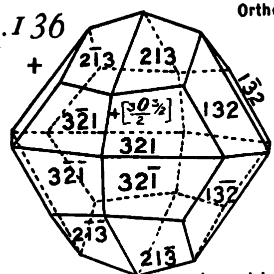
Orthorhombic

Fig.135



Orthorhombic

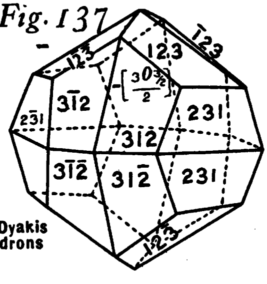
Fig.136



Diploid

Isometric Dyakis Dodecahedrons

Fig. 137



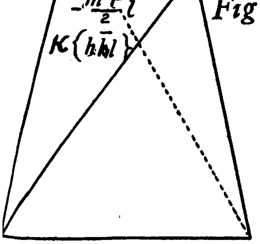


Fig. 142

Fig. 143

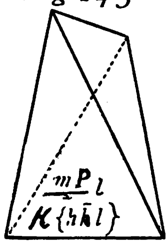
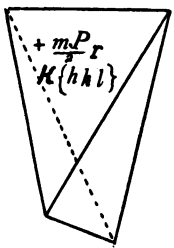


Fig. 144



Pl

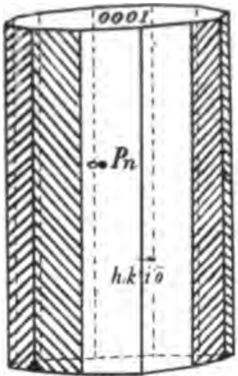


Fig.246

Dihexagonal
Prism

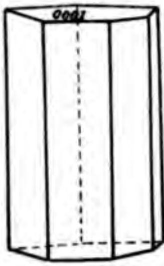


Fig.247

KT $\{i\bar{k}\bar{h}o\}$

$-\frac{\infty P\,n}{4}\,l$

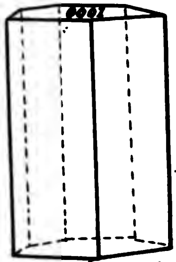


Fig.248

$\frac{\infty P\,n}{4}\,r$

KT $\{hk\bar{i}o\}$

Ditrigonal Prisms

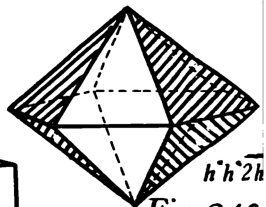


Fig.249

Secondary Hexagonal
Pyramid

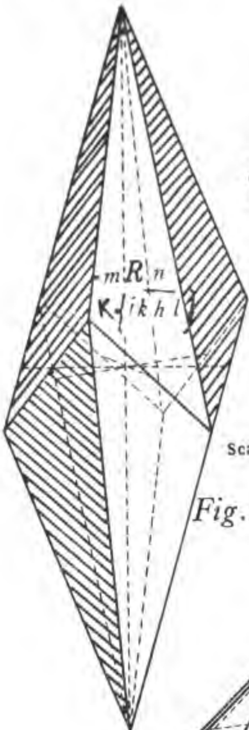


Fig.252

+

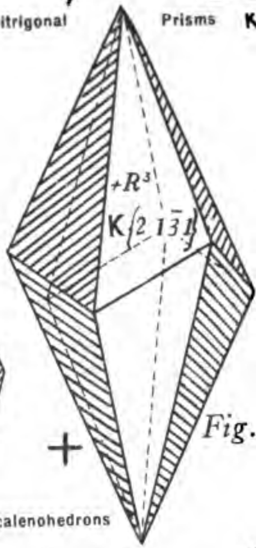


Fig.253

Scalenohedrons

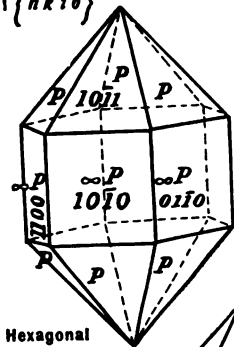
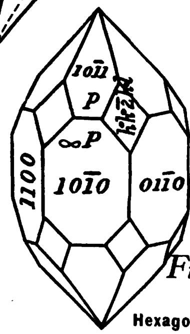


Fig.25

Hexagonal



Fig

Hexagon

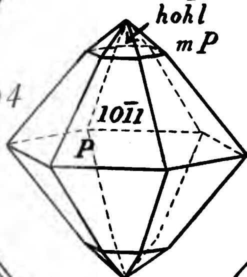


Fig.264

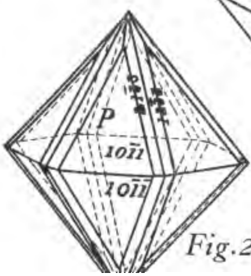


Fig.262

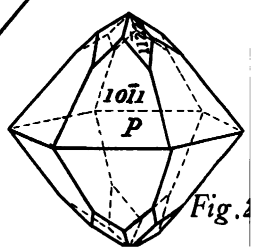


Fig.2

XI

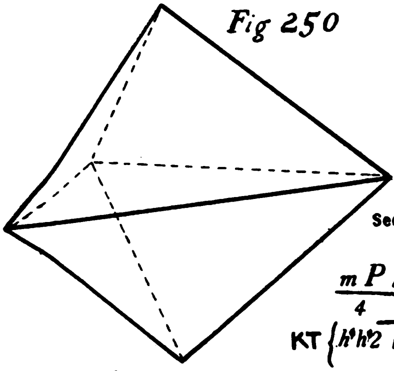


Fig 250

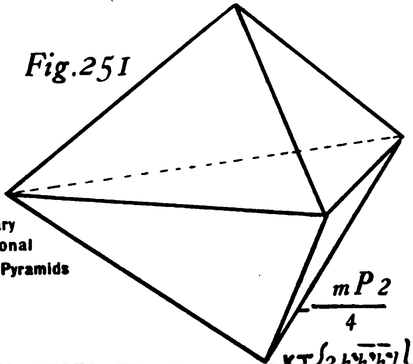


Fig. 251

Secondary Trigonal Pyramids

$\frac{mP2}{4}r$ KT$\{h^{\circ}h^{\circ}\bar{2}\ \bar{h}^{\circ}l\}$

$\frac{mP2}{4}$ KT$\{2\ h^{\circ}\bar{h}^{\circ}\bar{h}^{\circ}l\}$

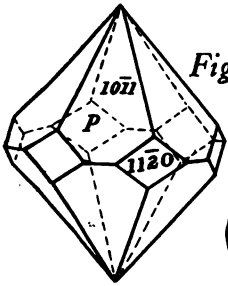


Fig. 256

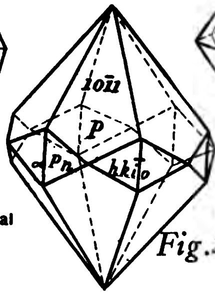


Fig. 257

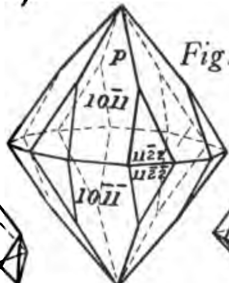


Fig. 258

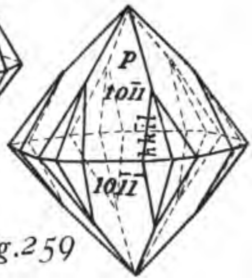
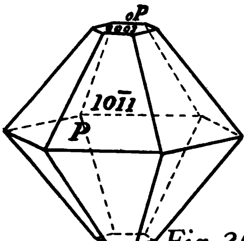


Fig. 259

Hexagonal Pyramids



55

Fig. 263

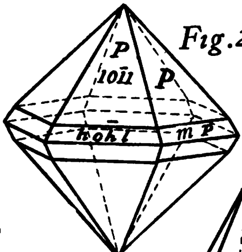


Fig. 260

Fig. 261

Hexagonal Pyramids

Pyramid

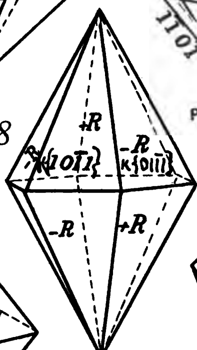


Fig. 268

2$\bar{1}\bar{3}$3

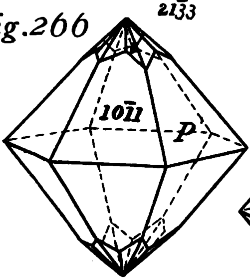
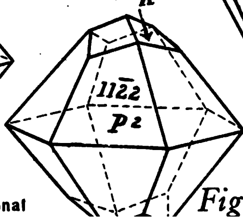


Fig. 266

h0hl
mR



Hexagonal

Fig. 267

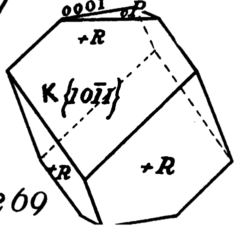
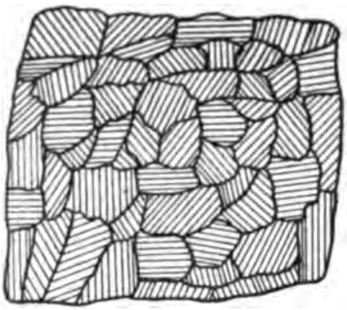


Fig. 269

Plate

Fig. 446



Mineral Aggregate

Fig 447 ∞O∞ 100

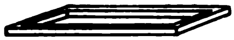


Fig. 448 ∞O∞ 100

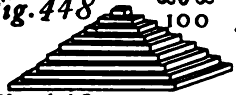
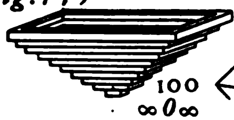


Fig. 449



Parallel

Fig. 450

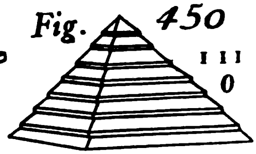


Fig. 451

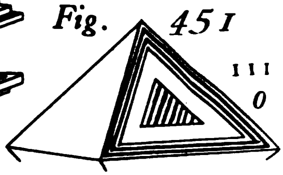


Fig 456

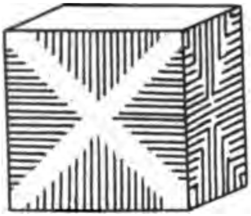
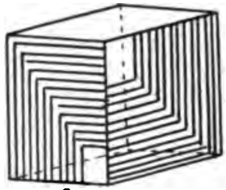
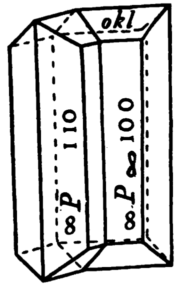


Fig 457



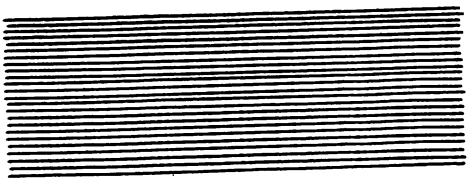
Parallel Growths

Fig. 458 $mP\infty$



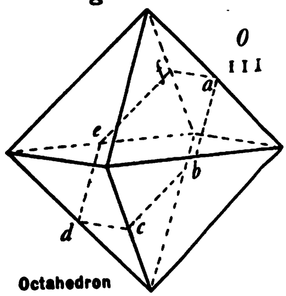
Twinning

Fig 462



Polysynthetic Twinning

Fig. 463



Octahedron

Fig. 467

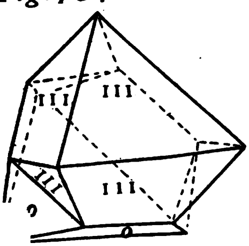


Fig. 468

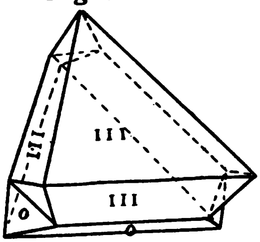


Fig. 469

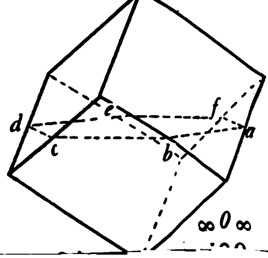


Fig. 452

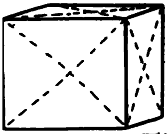
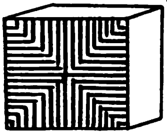
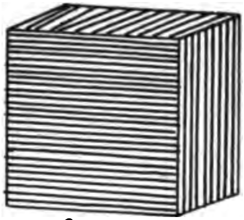


Fig 453



Growths

Fig 454



Parallel Growths

Fig. 455

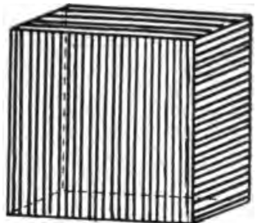
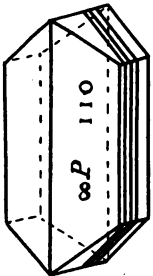
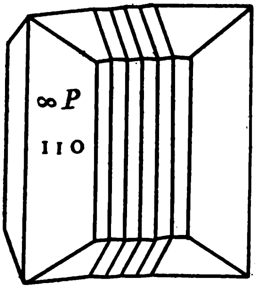


Fig. 459



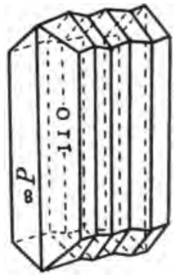
Polysynthetic Twinning

Fig 460



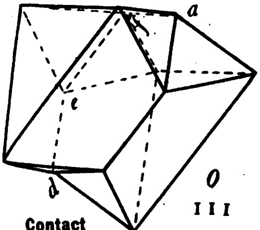
Polysynthetic Twinning

Fig 461



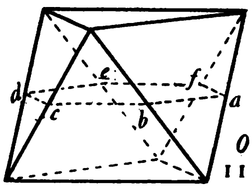
Polysynthetic Twinning

Fig 464



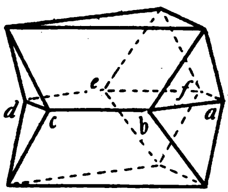
Contact Twin

Fig. 465



Octahedron

Fig. 466



Contact Twin

Fig. 470

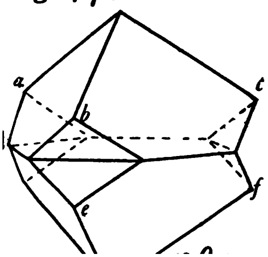


Fig. 471

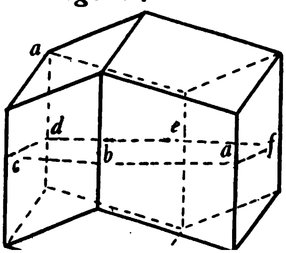
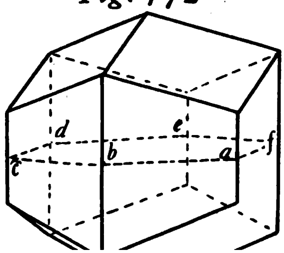


Fig. 472



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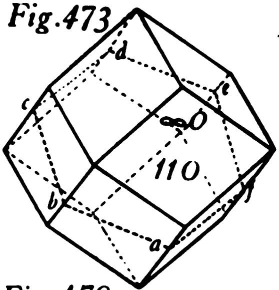

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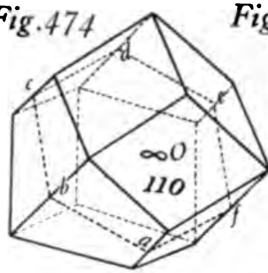

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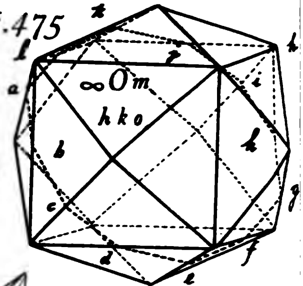

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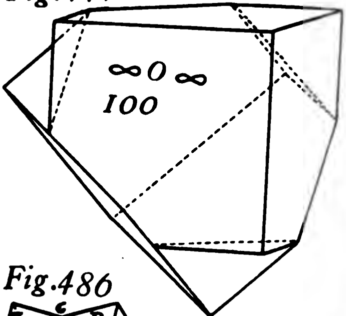

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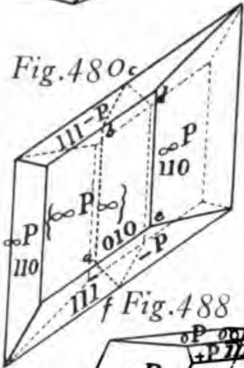

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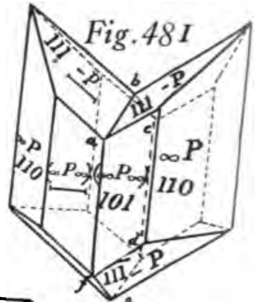

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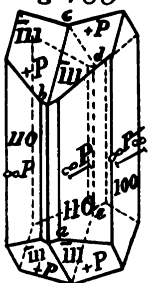
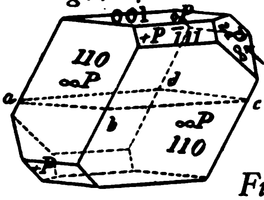


Fig. 487


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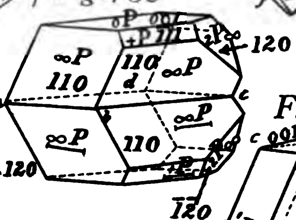

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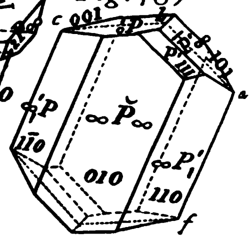

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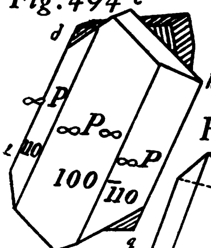

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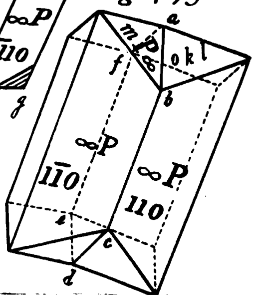

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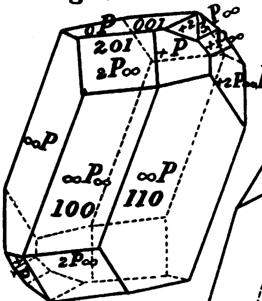

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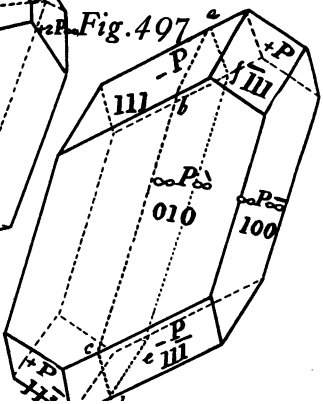


Fig.476

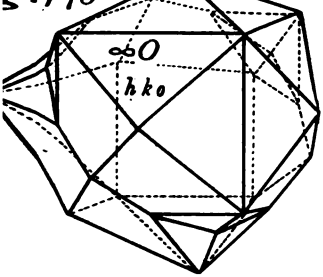
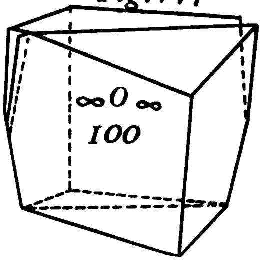


Fig.477



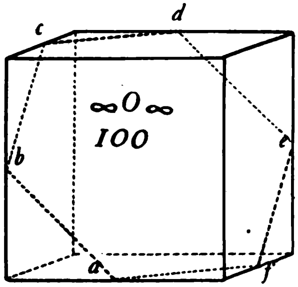
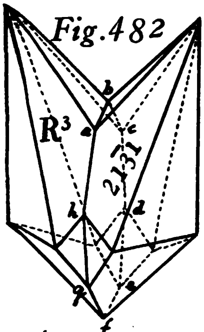


Fig.478

Fig.482



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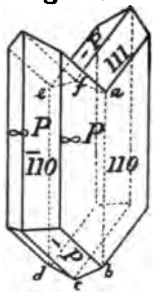
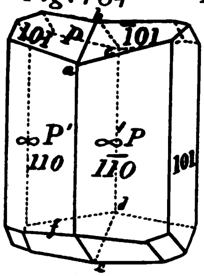


Fig.484



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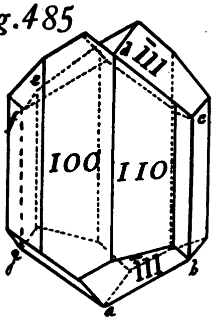


Fig.490

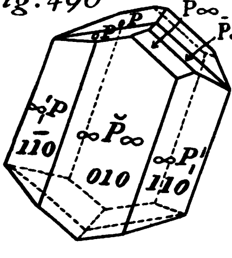
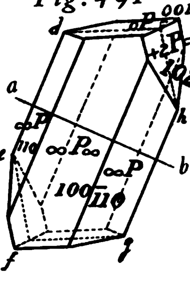


Fig.491



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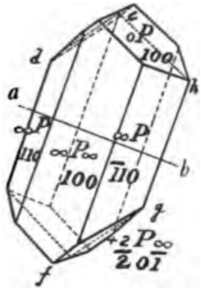

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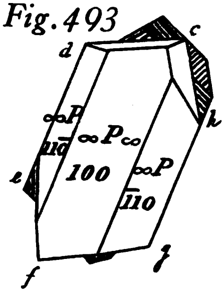

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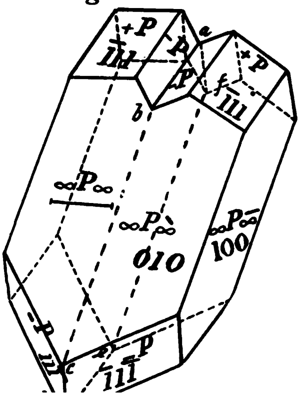

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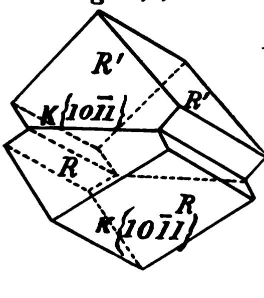
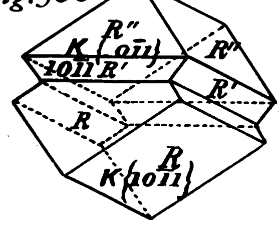


Fig.500



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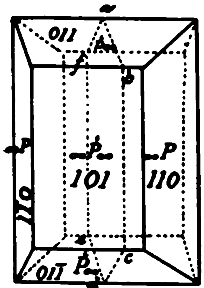

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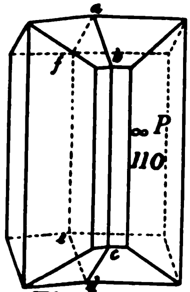

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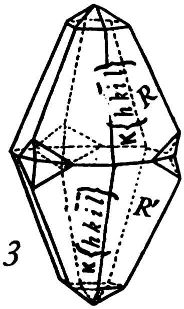


Fig. 503

Fig. 507

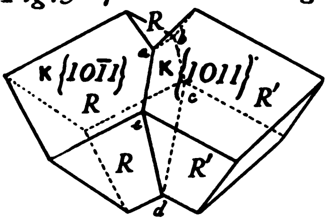
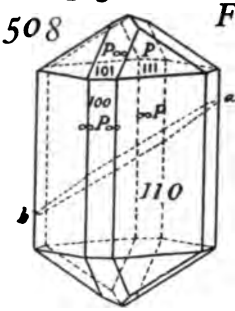


Fig. 508



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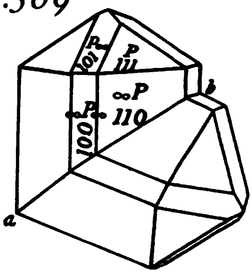


Fig. 512

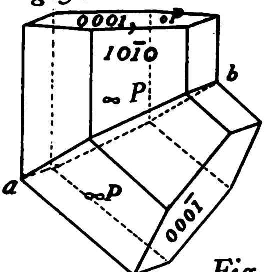


Fig. 514

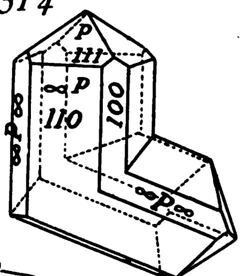
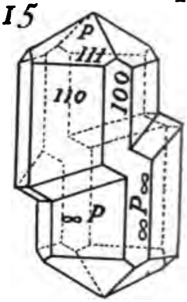


Fig. 515



Fig

Fig. 513

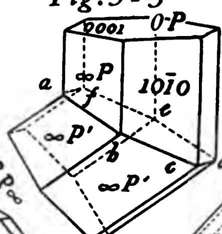


Fig. 519

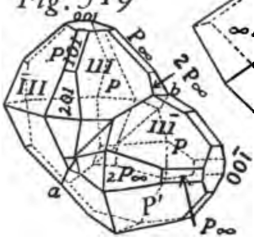
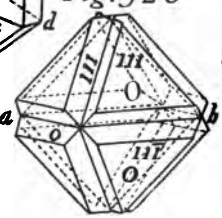


Fig. 520



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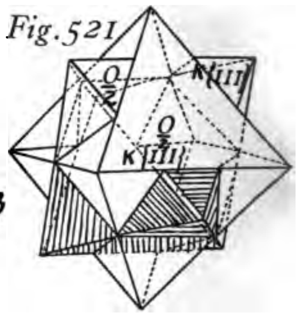


eXXI

r. 504

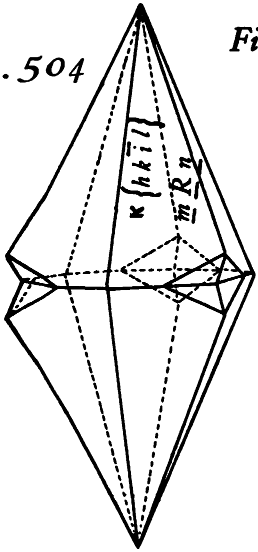
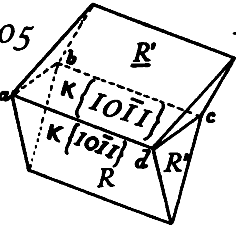


Fig. 505



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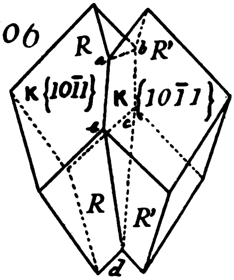


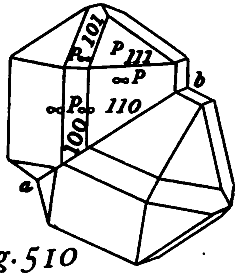
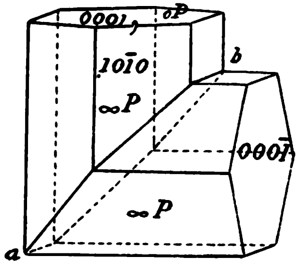


Fig. 510

Fig. 511



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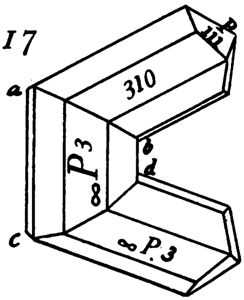

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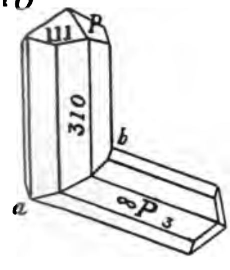

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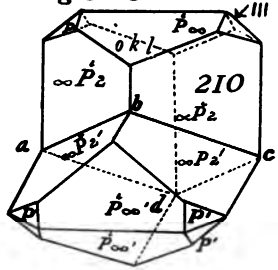
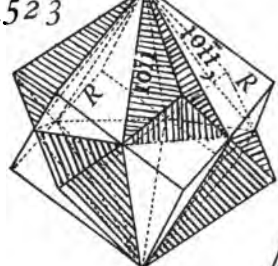


Fig. 523



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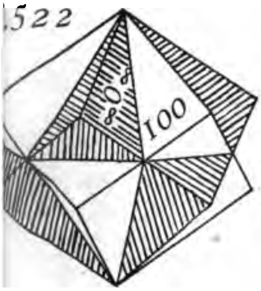

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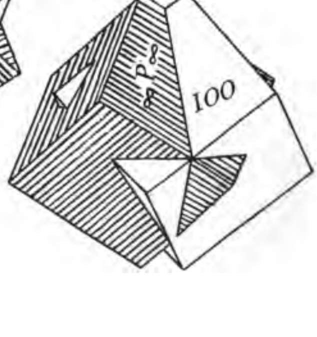

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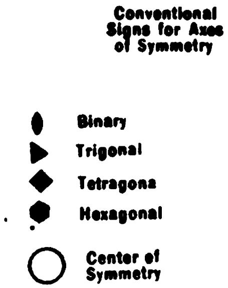


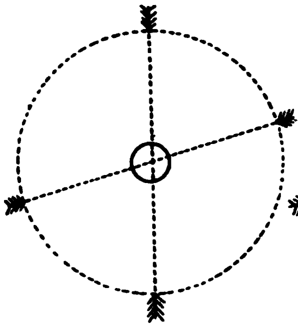


Fig 581

Triclinic

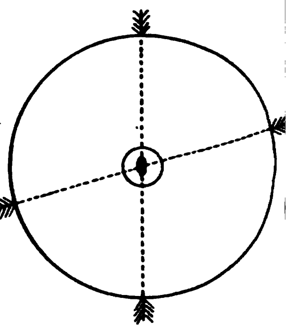


Fig. 582

Monoclinic

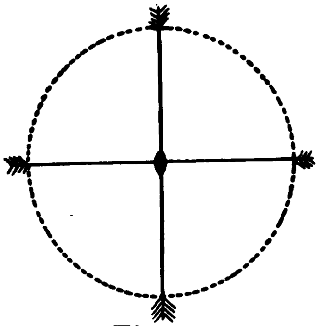


Fig. 586

Orthorhombic
Hemimorphic

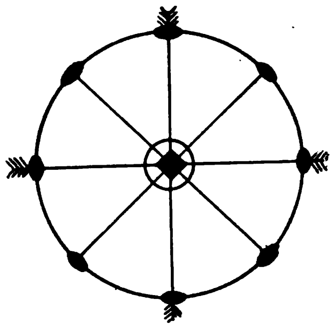


Fig. 587

Tetragonal
Holohedral

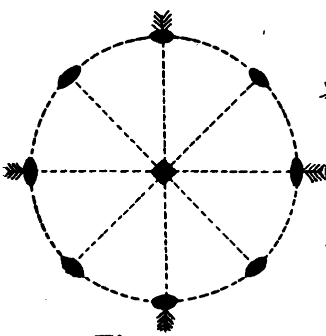


Fig. 590

Tetragonal
Trapezohedral

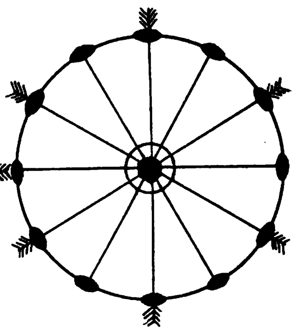


Fig. 591

Hexagonal
Holohedral

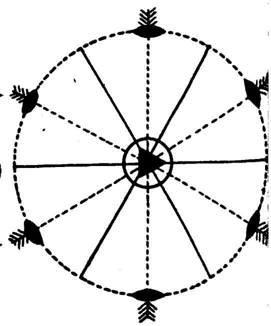


Fig. 592

Hexagonal
Hemihedral

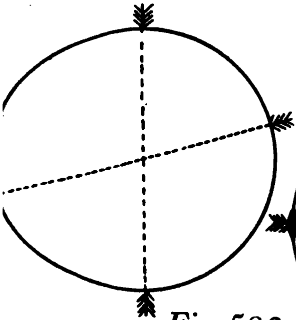
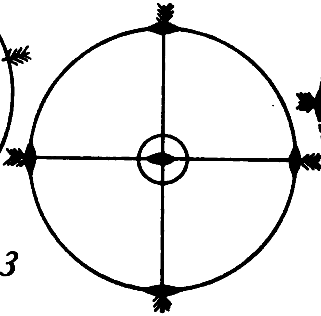


Fig. 583

Monoclinic
Clinohedral

Fig. 584



Orthorhombic
Holohedral

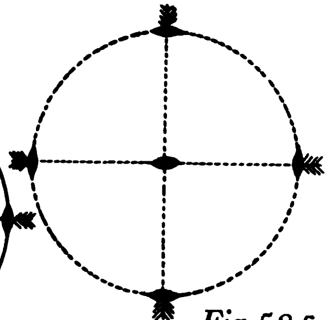


Fig. 585

Orthorhombic
Hemihedral

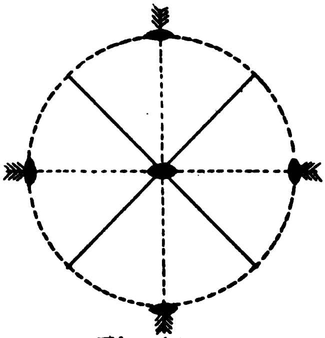


Fig. 588

Tetragonal
Sphenoidal

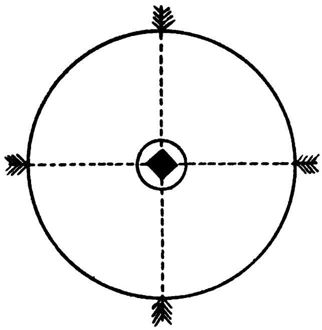


Fig. 589

Tetragonal
Pyramidal

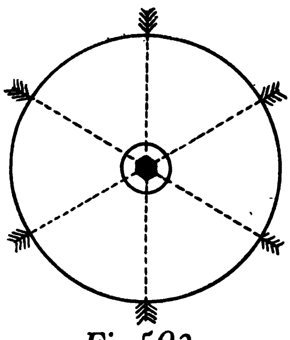


Fig. 593

Hexagonal
Hemihedral
Pyramidal

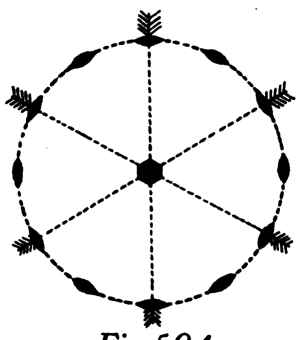


Fig. 594

Hexagonal
Hemihedral
Trapezohedral

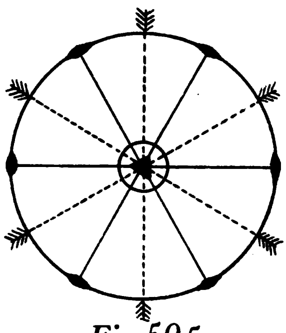


Fig. 595

Hexagonal
Hemihedral
Trigonal

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